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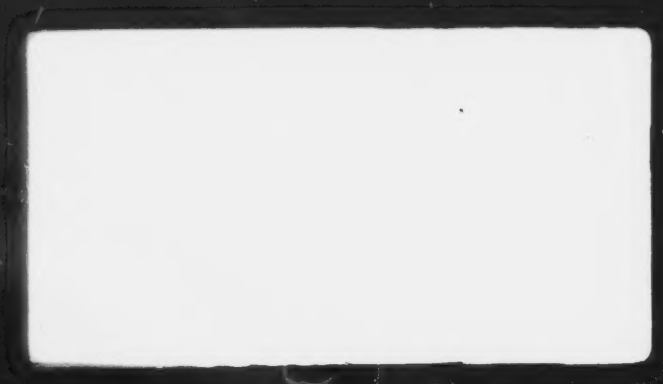

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A model which assumes a form of solution of the equation for a single source, inserts appropriate empirical parameters and sums the solutions over all sources is described. Three categories of source are recognized in the model: major, intense, discontinuous, i.e., point and line, sources (examples are the stacks of electrical generating or other major industrial plants and highways, etc.); numerous minor sources which are treated as continuous area sources; and sources beyond the boundary of the model. Special devices, effectively a sub-model, which were needed to deal with the proximity of very large sources, unknown in detail, in the area of New York City are described.

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A REGIONAL AIR QUALITY SIMULATION MODEL

(A DESCRIPTION OF THE CONNECTICUT AIR POLLUTION MODEL AS DEVELOPED BY THE TRAVELERS RESEARCH CENTER)

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September 1971

Prepared under Contract CPA 70-155 for Division of Meteorology, National Environmental Research Center, Environmental Protection Agency, Research Triangle Park, North Carolina

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A Regional Air Quality Simulation Model

1.0 Short-Term Air Quality Models

The purpose of a short-term (resolution of one hour or so) air quality model is to allow computation of the concentration of one or more atmospheric contaminants at one or more locations in a region. Finite time resolution implies that the computed results are time averages over the resolution period. Contaminant concentration is very variable in space and time, and it is impracticable to specify all sources in complete detail so that some averaging in space of both input and output is a feature of all air quality models.

We recognize two major categories of model - those which set up an equation to describe the transport and diffusion of emitted material and solve this by forward integration in time, and those which assume a form of solution of the equation for a single source, insert appropriate empirical parameters and sum the solutions over all sources.

2.0 The TRC Model

The model to be described is of the second kind. It was developed between 1966 and 1969 at the Travelers Research Center and it is convenient to describe it as "The TRC Model". Major contributors to its development were G. E. Anderson, F. I. Badgley, N. E. Bowne, K. Hage and G. R. Hilst. A brief description has been published by Hilst (1967). It has been applied to the State of Connecticut (Hilst, Yocom and Bowne, 1967) and to the environs of Toronto (Bowne, Boyer, Trent and Cooper, 1971). Both applications have been subjected to an extensive verification program, Hilst (1969) and Bowne et al (1971).

Three categories of source are recognized in the model:

a. Major, intense, discontinuous, i.e., point and line, sources. Examples are the stacks of electrical generating or other major industrial plants and highways, etc.

b. Numerous minor sources which are treated as continuous area sources.

The area of the model is divided by a square grid of side 'a'. All locations are referred to by the coordinates (i.j.) of this grid. The minor sources within each grid square are added, and the total assumed to be distributed evenly over the square. Thus, all space variability of the minor sources on scales less than one grid square is suppressed, and we cannot recover a meaningful pattern of the concentration variation caused by the minor sources on any smaller scale. There is also a limitation on time variability which is discussed later.

c. Sources beyond the boundary of the model.

No model can treat sources beyond its boundary as realistically as it can treat explicit internal sources, but ideally it should include all sources having a major influence on air quality within the region to which it is to be applied. The application of the TRC model to the State of Connecticut was complicated by the proximity of very large sources, unknown in detail, in the area of New York City. Special devices, effectively a sub-model, were needed to deal with this situation. They are described later.

3.0 The Gaussian Dispersion Formula

The TRC model employs empirically established formulae - the Gaussian dispersion formulae - to calculate concentrations of pollutants. In part the formulae are employed in an unorthodox manner and to understand the possibilities and limitations of the model it is useful to examine the conceptual and factual bases of the formulae and relate them to the way in which the formulae are incorporated into the model. The Gaussian formula describing the transport and dispersion of a puff of material emitted instantaneously from a point source at height H is

$$\chi_1(x,y,z,t) = \frac{Q}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z} \exp - \left[\frac{(x-\bar{u}t)^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2}\right] \left\{\exp - \left[\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp - \left[\frac{(z+H)^2}{2\sigma_z^2}\right]\right\} \quad (1)$$

where Q is the quantity of material emitted; x,y,z are coordinates with origin at the earth's surface perpendicularly below the source, which is at (0, 0, H); $\bar{u}$ is the mean speed of the wind transporting the material during the time, t, which has elapsed since the instantaneous emission; the x-axis is in the direction of this mean wind; and the σ's are the standard deviations,relative to the puff center along axes with origin ($\bar{u}t$, 0, 0), of the distribution of emitted material. Dispersion estimates represented by the standard deviations depend on atmospheric turbulence

and thus are empirical functions of time which are related to atmospheric stability. The standard deviations of concentration describe rather than explain or predict the concentration distribution. As written, eq. (1) is quite general; $\bar{u}$ and the σ's may change with change of the time scale for which they are defined and there is no restriction to steady meteorological conditions. Note that if the wind direction varies with time, the x and y axes are only locally 'cartesian'. On a larger scale the x axis is bent to conform to the generally curvilinear wind trajectory. The y distance is then measured along the local normal to the trajectory. This system, commonly used in fluid flow analyses, is referred to as a stream-oriented coordinate system.

If the puff formula is to be <u>useful</u> in prediction or post-facto explanation of observed concentrations, there must be some generally applicable specification of the σ's. It is possible to specify them as empirical functions of time, (i.e., time elapsed since emission) and 'atmospheric stability'. It is also possible by grouping 'atmospheric stability' into a few (four to six) broadly specified classes, to limit the number of empirical functions required, the functional relations being determined by field trials. This limitation on σ,t relationships limits the generality of the formula - it now refers only to circumstances when 'atmospheric stability' is steady. There is no explicit restriction to steady mean wind, but wind speed is one of the factors normally used in the assessment of 'atmospheric stability'.

The Gaussian formula describing dispersion of material from a

continuous point source is

$$\chi_2(x.y.z) = \frac{Q}{2\pi\,\sigma_y\,\sigma_z\,\bar{u}} \exp - \left[\frac{y^2}{2\,\sigma_y^2}\right]$$

$$\left\{\exp - \left[\frac{(z-H)^2}{2\,\sigma_z^2}\right] + \exp - \left[\frac{(z+H)^2}{2\,\sigma_z^2}\right]\right\} \qquad (2)$$

where Q is now the rate of emission of matter. We may regard eq. (2) either as being empirically established independently of eq. (1) or as being derived for any (x, y, z) by integration of eq. (1) over time, regarding the continuous point source as an infinite series of puffs with non changing σ_x as the puff passes a point,

$$\text{i.e.,}\quad \chi_2 = \int_{-\infty}^{\infty} \chi_1(t)\, dt$$

Eq. (2) is essentially a steady state formula. Regarded as an empirical formula independent of eq. (1) it requires specification of a mean wind $\bar{u}$ steady in both magnitude and direction to define the plume axis. The σ's are found to be empirical functions of x, the functional dependence varying with atmospheric stability. It can be derived for any x by time integration from eq. (1) only if $\bar{u}$ is independent of time and if the σ's (which may be functions of x) do not vary explicitly with time. Application of eq. (2), therefore, presumes steady mean wind and unchanging atmospheric stability. The approximation of stream-oriented coordinates is, however, acceptable if the wind direction changes slowly with time. In that case, the plume center-line coincides with the

trajectory.

The Gaussian formulae eq. (1) and eq. (2) have been confirmed by observations made over fairly uniform terrain in reasonably steady conditions of wind and atmospheric stability. These observations show that the Gaussian distribution is a reasonable description of the average concentration distribution in an ensemble of puffs, and of the variation of concentration across a plume for averaging times of order one hour. There is more and more satisfactory evidence for the plume formula than for the puff formula. In trials such as these, the σ's are established as empirical functions of time or distance from source, and of atmospheric stability. Deviations of the results of individual trials from the average of several trials may typically be more than a factor of 2 in one trial out of five. Given this degree of imprecision in single applications of the formulae, it follows that inconsistencies of application likely to produce random errors of the same order are not serious defects of a Gaussian formula model. We must, however, examine all inconsistencies to ensure that they are not likely to produce systematic error.

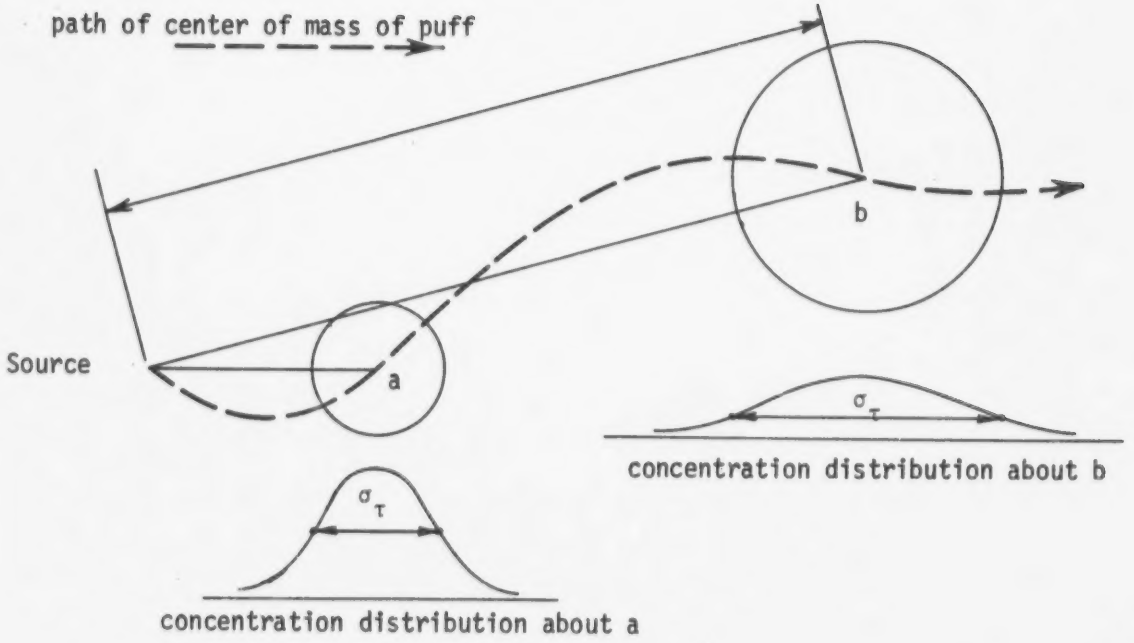

Fig. 1. Illustrating the puff formula in two dimensions.

4.0 Trajectories and Multiple Sources

In explaining how the formulae are incorporated into the TRC model, it is convenient initially to ignore the dispersion in the vertical (treatment of which in practice often calls for substantial modification of the Gaussian formula). For the present, therefore, we consider only the horizontal dispersion terms. In the TRC model, it is assumed that $\sigma_x = \sigma_y = \sigma$.

When using the model the computational requirements can be reduced by considering only those sources making an appreciable contribution to pollution concentration at chosen receptors. To do this the trajectory of the air which surrounds the receptor point at the required time is tracked backwards across the model grid, and the contributions of only those sources within a corridor of a given width along the trajectory are summed to give the total concentration at the receptor. Fig. 2 illustrates the method. S_1 and S_2 are the strengths of sources (assumed at ground level for convenience) which emit puffs at time t_o. At some later time $t_o + t$ the concentration at a point R_1 is

$$\chi = \frac{1}{(2\pi)^{3/2}\,\sigma^2\,\sigma_z}\left[S_1 + S_2 \exp - \left(\frac{b^2}{2\,\sigma^2}\right)\right] \qquad (3)$$

i.e. the emissions at any time from multiple instantaneous sources surrounding a source S_1 on the trajectory can be replaced by the emission of a virtual source at S_1 obtained by summing the intensities of the sources, and each weighted by a Gaussian factor depending on its distance, b, from S_1 and the appropriate σ. A similar argument applies to continuous

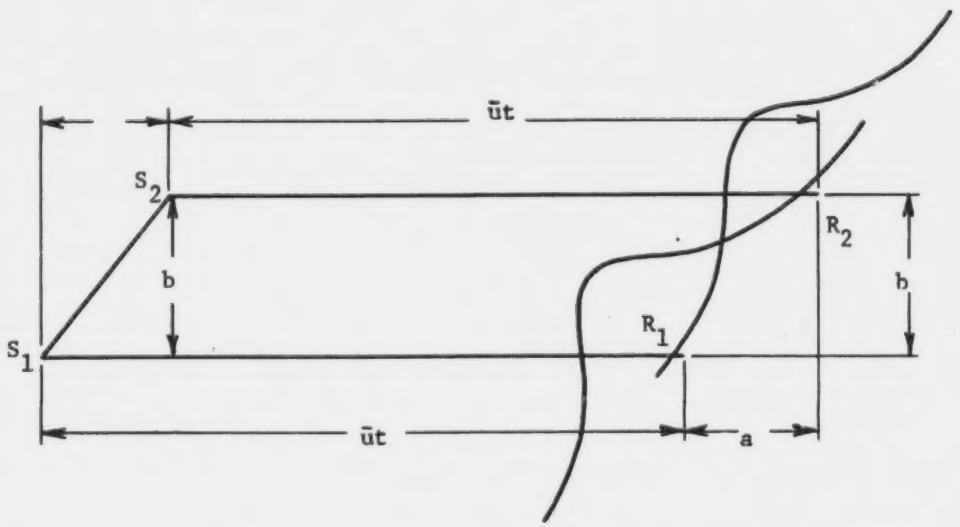

Fig. 2. Concentration distribution from multiple sources.

sources if σ is replaced by σ_y, i.e., a distribution of continuously emitting sources on any perpendicular to the trajectory can be replaced by a single source on the trajectory with an intensity equal to a weighted sum of all the source intensities.

5.0 Aspects of the Application of the Gaussian Formulae in the TRC Model

5.1 Peculiarities of Application

We are now in a position to examine aspects of the application of the Gaussian formulae in the TRC model. Some of these are common to all multiple-source plume or puff models, some are peculiar to the TRC model. During any one computation of the concentration at a receptor -

1. The instantaneous point source ("puff") formula is used for finite area sources emitting for finite times. The emission rate for a single area of side a is assumed to remain constant for the basic definition time of the model, usually one or two hours.

2. The infinite integration limits of the Gaussian formulae are replaced by finite limits -- many sources are neglected in computing the concentration at any one receptor. Gaussian formulae require integration between infinite limits even though 99 percent of the area under a Gaussian curve lies within the limits of $\pm 3\sigma$. The integration used in the model, described in Sections 5.3 and 6.4 assumes 100 percent of the area within finite limits.

3. The model necessarily neglects temporal variation of the functional dependence of the σ's on time and distance.

4. The model includes spatial variation of the mean wind vector, but also employs the continuous source (plume) formula for major sources. The simple Gaussian plume model of eq. (2) assumes straight-line flow at constant wind speed. We permit changes in the flow over the region and assume a plume model as described in Section 5.2.

5. The model includes temporal variation of the mean wind vector. The wind fields are permitted to change at the basic definition time of the

model, usually one or two hours. This permits the wind field to be changed to account for time changes at an interval that reasonably represents observed information.

Of these five points the third refers to an aspect of the real physical situation which is not accounted for by the model because the Gaussian formulae do not permit it. Points four and five refer to aspects of the real physical situation which the model attempts to account for in spite of the fact that formally the Gaussian formulae do not permit it. Points one and two concern approximations which are essential in order to restrict computation to acceptable limits. We will consider them in turn and discuss the errors, random and systematic, which they are likely to introduce, but before doing so it is necessary to outline the computational procedure.

5.2 General Description of the Computation

The first step is to compute from the windfield the trajectory of a material particle which occupies the receptor point at the time at which pollutant concentration is required. Details are given in Section 5.6 and the result is illustrated in Fig. 3. Here $\alpha(I,J)$ is the receptor point and the trajectory is identified (stored in the computer) by the points at which the trajectory crosses the grid -- (η,ζ) and (μ,ν) are representative points in Fig. 3. At these points one coordinate (i or j) is integral, the other normally non-integral. The windfield and source inventory are held constant for two-hour periods. They may be changed at the beginning of each period. In Fig. 3, points β and γ on the trajectory illustrate the effects of such a change. The trajectory itself is defined by the straight line segments between the crossing points. Distance along the trajectory

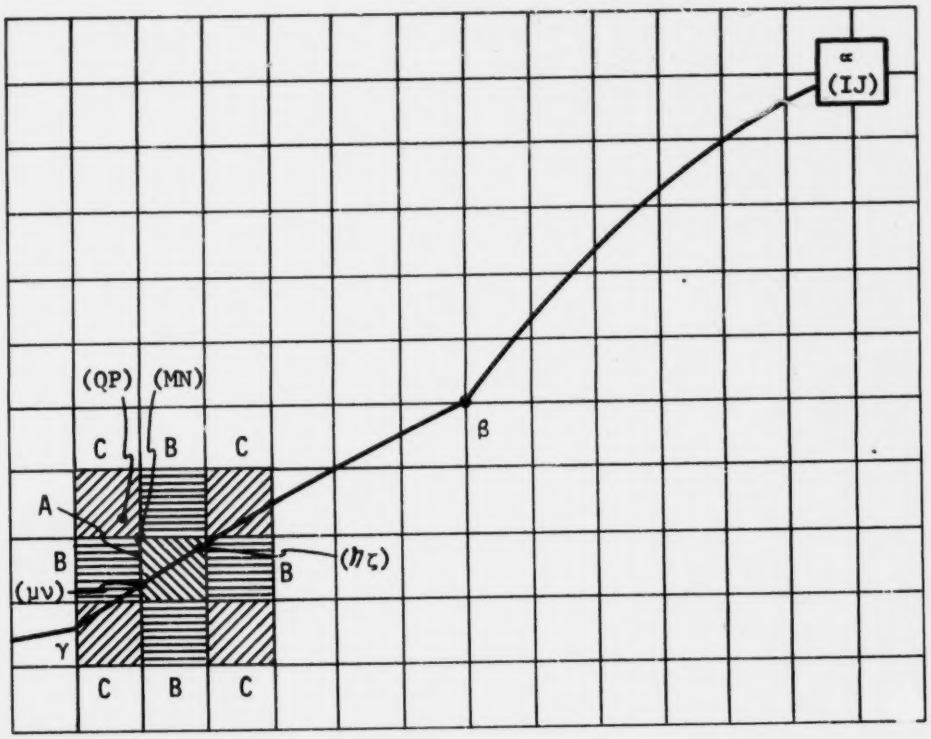

Fig. 3. Sources, trajectory and receptor.

and elapsed time between the receptor and all crossing points are known, as is the time spent within each grid square. The contribution of real and virtual sources within each on-trajectory grid square to the concentration at α is then computed from the puff formula as expressed in eq. (3), the puff intensity being taken as the product of the time the wind takes to cross the grid square and the total rate of emission of sources within the square at the time at which the trajectory crossed the square. (Section 5.4). The elapsed time (or source -- receptor distance) required for selection of the appropriate σ values is taken as the time or distance on trajectory from the receptor to first contact with the source square (e.g., for Square A in Fig. 3 time or distance between (I,J) and (η,ζ), plus a time 'correction' $a/2\bar{u}$ or a distance 'correction' $a/2$ where $\bar{u}$ is the mean wind at α(I,J) speed and a is the length of the grid side. (Section 5.4).

Major point sources are treated according to the plume formula eq. (2). In the Connecticut application they are considered to be located at the nearest grid intersection, e.g., in Fig. 3 a major source actually at (O,P) is considered to be located at (M,N). The source-receptor distance (x) used in the computation is the distance from receptor to the trajectory-grid crossing-point nearest to the conventional location of the source (distance (I,J) - (μ,ν) in Fig. 3). The off-axis distance (y) is taken as the shorter of the distances from the conventional source position to the trajectory measured along the grid axes, (distance (M,N) - (μ,ν) in Fig. 3). These approximations are required because the trajectory is not more closely defined in the computer store than by the crossing-points. They are not essential features of the TRC model but are used in the Connecticut application. In general neither x nor y need necessarily be an integral multiple

of the grid side. In the Toronto application, locations of point sources are not restricted to integral grid points.

5.3 Quadrature and Truncation of the Gaussian Distribution

We are now in a position to consider the peculiarities of the model set out in Section 5.1. The first concerns the use of the instantaneous point source formula with a finite area source. Although we have described the receptor as a 'point' the suppression of source detail on scale less than the grid square implies that it is meaningless to compute a concentration pattern on less than this scale. The 'receptor' becomes an area equal to the grid square, centered on the point chosen as the receptor (e.g., the area surrounding α in Fig. 3). It then also becomes meaningless to employ the continuous Gaussian distributions which would imply concentration variations across the receptor area. The Gaussian functions are therefore replaced, in the area source computation, by a rectangular stepped distribution of the type shown in Fig. 4; each continuous two-dimensional Gaussian distribution being replaced by $(2n + 1)^2$ factors where n is the number of square grid rings surrounding the central source square. This procedure also facilitates truncation of the Gaussian distribution with corresponding limitation of the number of area sources considered in the computation of the concentration at any one receptor. In the Connecticut application truncation was at $n = 1$, as illustrated in Fig. (4). At Toronto $n = 2$ has been used. The method of calculation of the factors is explained in Section 6.4. Referring again to Fig. 3, we see that the contribution to the concentration at (I,J) which can be attributed to the time the center of mass of the air surrounding (I,J) spent in square A, between (η,ζ) and

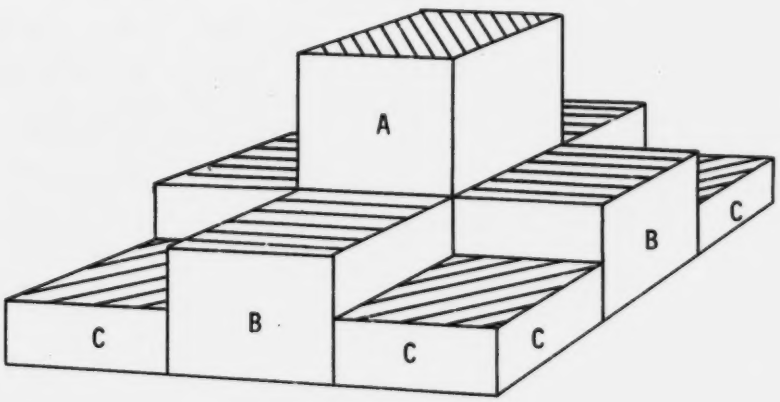

Fig. 4. Quadrature and truncation of the Gaussian distribution.

(μ,ν) is computed by summing, for square A and the eight contiguous squares, the product of the time spent between (η,ζ) and (μ,ν), the source intensity, and the appropriate Gaussian factor A, B, or C. The total contribution of area sources to the concentration at A is the sum of such sums computed for each square transected by the trajectory. (Note that we are still not considering vertical diffusion.)

In the Connecticut application of the model the continuous Gaussian distribution was used in computing the contribution of major continuous point sources, a procedure not consistent with the treatment of area sources, but not an essential feature of the model. A more consistent procedure would be to attribute to each receptor the average of the continuous distribution of concentration over a segment of y of length a (the grid-length), centered on the receptor point.

There is no obvious reason why these procedures, spatial averaging and truncation, should produce errors so long as computed grid-square averages of concentration are compared with actual grid-square averages. In fact, spatial averages of contaminant concentrations are not measured and it is obvious that there can be both random and systematic differences between the actual point measurements commonly made and true area averages. The procedures should not produce <u>systematic</u> errors in grid-square averages of concentration if the whole area of the model is considered, because the truncated Gaussian distributions are normalized to the integral between infinite limits. However, it seems likely (because there are prevailing winds) that locally systematic errors could occur close to concentrations of strong sources. A fairly even spread of sources over the model area would be conducive to small random or systematic error.

5.4 Finite Emission Time and the Puff Equation

Two major difficulties arise in using the puff equation with an extended source and a finite emission time. The first is to establish the source strength Q. This has been taken as the product of the time the wind takes to cross the grid square and the total rate of emission of sources within the grid square at the time at which the trajectory crossed the square.

This is an assumption: its validity has not been quantitatively analyzed. Intuitively it appears reasonably sound when the segment of the trajectory falling within the grid square is substantial, or when there is no large change in source intensity between contiguous grid squares. It might be responsible for considerable errors, systematic only because there are prevailing winds, at receptor points close to regions in which there are steep spatial gradients of source intensity.

The second major difficulty in using the puff equation with a source of finite emission time is in deciding the appropriate value of σ, which is a non-linear function of time elapsed since emission. The problem is obviously most serious for those sources near the receptor where the finite emission time is comparable with the elapsed time. The elapsed time actually used to calculate the Gaussian factor for emissions from any square is the trajectory time to the contact point nearest to the receptor (i.e., (η,ζ) for square A in Fig. 3) plus $a/2\ \bar{u}$ where $\bar{u}$ is the mean wind speed at the receptor. This is obviously a reasonable device not likely to lead to major random or systematic error, but capable of making minor contributions to both.

5.5 Time-Variation of the $\sigma(t)$, $[\sigma(x)]$ Functions

The general structure of the model allows change in the intensity of the sources and the meteorological parameters - wind speed, direction and stability - on a discontinuous basis. In the Connecticut application the change was allowed at two-hourly intervals. Changes in wind field and source inventory are accommodated in the manner described in Section 5.2. In Section 3 we have seen that change of stability presents one difficulty which is inherent in the Gaussian formulae - the functional relation between σ and elapsed time or distance cannot change along a trajectory. The convention adopted in the TRC model is to use the σ's appropriate to the stability existing at the time for which the concentrations are required. It is not obvious whether this convention, acting through the horizontal diffusion parameter σ_y, will produce systematic error. Sensitivity analyses, Hilst (1970), shows that the overall effect of changing σ_y is small, at least for the Connecticut source distribution. However, systematic error might be introduced through σ_z, because concentration computations made at the end of a period of increasing vertical stability (decreasing σ_z) will overestimate concentration, and computations at the end of a period of decreasing stability (increasing σ_z) will underestimate concentration. In general, underestimation in the hours after dawn and overestimation in the hours after dusk would be expected. The existence of elevated sources complicates this argument, but they are not a major feature of the Connecticut application of the TRC model.

5.6 Space and Time Variations of the Mean Wind

The method of computing the wind field allows variation in speed

and direction over the grid. A new wind field is computed for each two-hour period. In Section 5.2 we have seen how these variations are incorporated into the trajectory computation. No difficulty arises from this variation of $\bar{u}$ in the instantaneous point source formula, and in the extension to grid square sources $\bar{u}$ enters only in the computation of the time for which a particular square is contributing to the required concentration. Section 3 shows that $\bar{u}$ within the source square should be, and is, used in determining this time.

Difficulty arises with the continuous source formula used for major point sources, which requires a constant $\bar{u}$ to define the plume axis as well as the source strength. It is clear that so far as source strength is concerned, the $\bar{u}$ to use in the formula is that appropriate to the source. In the TRC model the $\bar{u}$ of the Gaussian formula is replaced by distance along trajectory, i.e., the mean wind used implicitly to compute source-receptor distance and to select σ is not necessarily the same as that used where it appears explicitly in the concentration formula. Fig. 5 illustrates the plume model with a curved centerline. The lower illustration in Figure 5 shows the conventional Gaussian plume model applied at distance x downwind from the source and at distance y perpendicular to the plume centerline. The upper illustration shows how the TRC model assumes the plume centerline to be parallel to the trajectory and y represents the distance from the trajectory point to the source point, but not necessarily a perpendicular distance. This use of non-perpendicular distances could result in systematic underestimation of the effect of a point source on the receptor.

The major causes of systematic spatial wind variations over an area

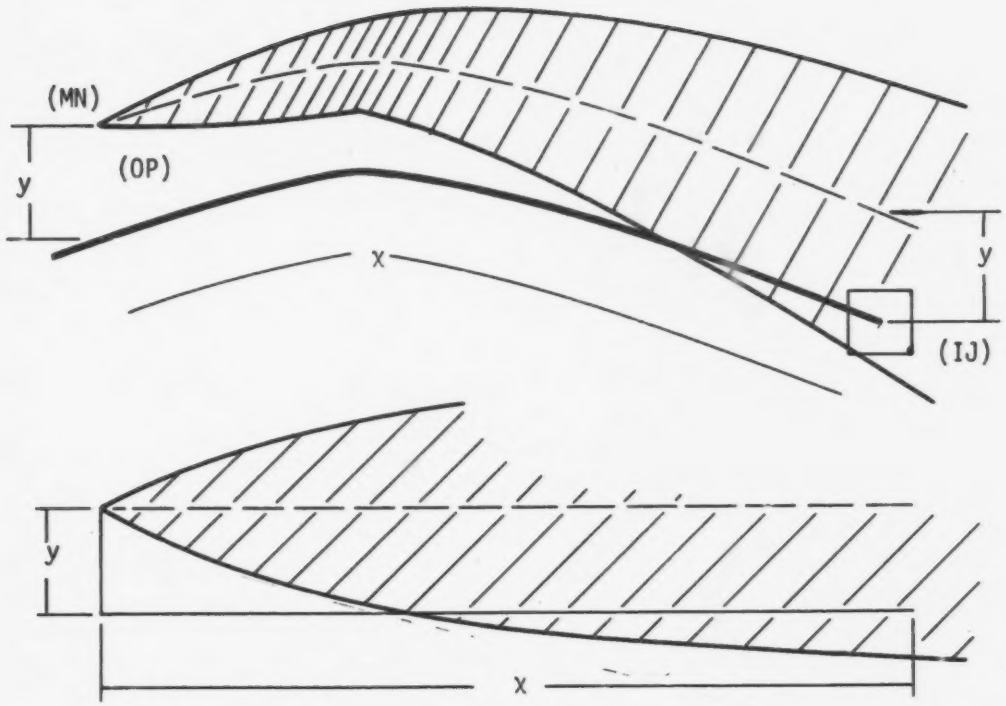

Fig. 5 Plume with curved trajectory.

the size of Connecticut or less are judged to be topography and differential thermal effects. (Both are treated in the Toronto application of the TRC model; topography is allowed for in the Connecticut version.) The model is considered to account satisfactorily for the grid scale features of topographic effects upon the windfield. In the Connecticut application no attempt is made to vary the dispersion parameters (σ's) which are known to be affected also by topography and thermal stability. In the Toronto application the effect of the city on diffusion is recognized by the use of σ's appropriate to urban conditions. The model might be subject to systematic error in localities affected, for example, by persistent lee eddies on the scale of the grid side or less. If this error exists, it is not a product of any procedure adopted in the model, but rather of an omission of detail.

5.7 The Decay of Contaminant

Gaussian formulae such as eqs. 1 and 2 were developed to account for the distribution of conserved contaminants — the normalizing constants ensure that the total source material is accounted for if the plume or puff is integrated over space. Material emitted into the atmosphere may be lost or transformed in various ways — it may react chemically with another contaminant or a permanent atmospheric constituent, it may fall out or be washed out, or it may decay spontaneously, in the manner of a radioactive substance. This last type of decay can be handled by the formulae, since the continuity equation for mass is satisfied if we replace the source term Q by Q exp ($-\lambda T$) where λ is a decay coefficient

$$\frac{\partial \chi}{\partial t} = - \lambda \chi$$

and T is the elapsed time since emission.

The device adopted in the TRC model to account for loss of contaminant is to characterize this loss, in fact due to processes unknown in detail, by a decay coefficient λ or a half-life τ, and regard the source as virtually time-dependent, amending eqs. (1) and (2). Eq. (1) then becomes

$$\chi_1(x,y,z,t) = \frac{Q \exp(-0.693\, t/\tau)}{(2\pi)^{3/2}\, \sigma_x\, \sigma_y\, \sigma_z} \exp -\left[\frac{(x-\bar{u}t)^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2}\right]$$

$$\left\{\exp -\left[\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp -\left[\frac{(z+H)^2}{2\sigma_z^2}\right]\right\} \qquad (4)$$

and eq. (2) becomes

$$\chi_2(x,y,z) = \frac{Q \exp(-0.693\, x/\bar{u}\tau)}{2\pi\bar{u}\, \sigma_y\, \sigma_z} \exp -\left[\frac{y^2}{2\sigma_y^2}\right]$$

$$\left\{\exp -\frac{(z-H)^2}{2\sigma_z^2} + \exp -\frac{(z+H)^2}{2\sigma_z^2}\right\} \qquad (5)$$

6.0 Operating Procedure

6.1 Derivation of the Mean Wind Field

When the TRC model was under development it was assumed that a basic wind field over the model region would be obtained by interpolation between observed "surface" winds. Early in the verification program for the Connecticut application of the model it was found that this method was unsatisfactory. Too few observations were available, and those that were were clearly affected by local influences of sub-grid-scale size. It was decided to develop a specification of the wind field which accounted for the influence of topography on scales greater than the grid scale. The method in principle assumes that there is a height in the atmosphere above which the effect of topography can be neglected; in particular there is no vertical motion through this surface. At the ground there is vertical motion -- the wind blows parallel to the surface, and thus has a vertical component. The average horizontal wind between the ground and the lid is computed from the mass-conservation equation.

Details of the topographic wind analysis were described by Anderson (1971).

6.2 Derivation of the Trajectories

The model computes concentration at chosen receptor points at chosen times. The first stage in the computation is determination of the trajectory of a material particle travelling with the mean wind which, at the chosen time, is situated at the receptor point; i.e., the air surrounding the receptor point is followed backwards in time. The requirements are to

identify the grid squares through which the imaginary material particle has passed, and to determine the time spent in traversing each of these squares.

The wind field is stored as a stream function ψ on each grid square so that local velocity components are derivatives of the stream function. The derivatives and finite difference forms are:

$$u = -\frac{\partial \psi}{\partial y} = u(i,j) = -[\psi(i,j+1) - \psi(i,j-1)]/2a \qquad (6)$$

$$v = \frac{\partial \psi}{\partial x} = v(i,j) = [\psi(i+1, j) - \psi(i-1, j)]/2a \qquad (7)$$

where a is the grid-length.

The wind field is assumed to be constant for some basic period, typically two (2) hours, and then to change discontinuously. The routine is entered at grid point $\alpha(I,J)$, (Fig. 3) representing the location of the desired air quality estimate. A counter, k, is set to one and will change by one increment for each time step. The local u and v wind components are obtained from eqs. (6) and (7) and an initial time step Δt (typically 15 minutes) is chosen to determine the local trajectory line segment.

Then:

$$\Delta\pi(1) = -u(1)\,\Delta t/a$$

$$\Delta\kappa(1) = -v(1)\,\Delta t/a$$

$$V(1) = (u^2(1) + v^2(1))^{1/2} \qquad (8)$$

where $\Delta\kappa$ and $\Delta\pi$ are the j and i components of displacement expressed in

terms of the grid length a and (1) denotes that the displacements correspond to the first time step. Tests are applied to determine if $0.3 \leq (\Delta\pi \text{ or } \Delta\kappa) \leq 1$. If not, then Δt is doubled or halved and the process is repeated. The upper limit ensures that at each step i and j do not change by more than 1, while the lower limit is used to limit the number of computations required. Δt may be different for different portions of the trajectory.

Further points on the trajectory are computed from

$$\pi(i+1) = \pi(i) + \Delta\pi$$
$$\kappa(i+1) = \kappa(i) + \Delta\kappa \qquad (9)$$

These points are tested to see if the edge of the model grid array has been reached, if not the process is repeated. A secondary check limits the total number of trajectory points to a maximum of 200.

At this point a trajectory has been calculated backwards from the point of interest to the edge of the regional grid with a series of short line segments and has been defined by the stored (π,κ), coordinates of the end points of the line segments. The corresponding wind speeds have been calculated and stored in a companion array.

An example of such a trajectory pattern is shown in Fig. 6. The number above the point represents the counting index k associated with it. The next step is to express the trajectory as the series of all the points at which it (the trajectory) intersects the lines of the basic grid, i.e., points for which either of π, κ, but not necessarily both, is an integral value of j or i. This step results in a set of trajectory points

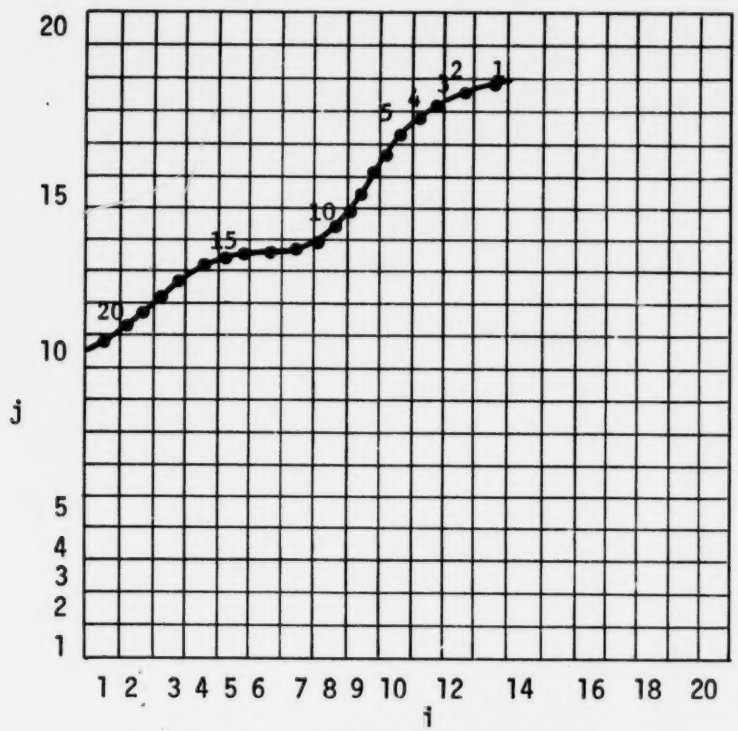

Fig. 6. Trajectory and stored points.

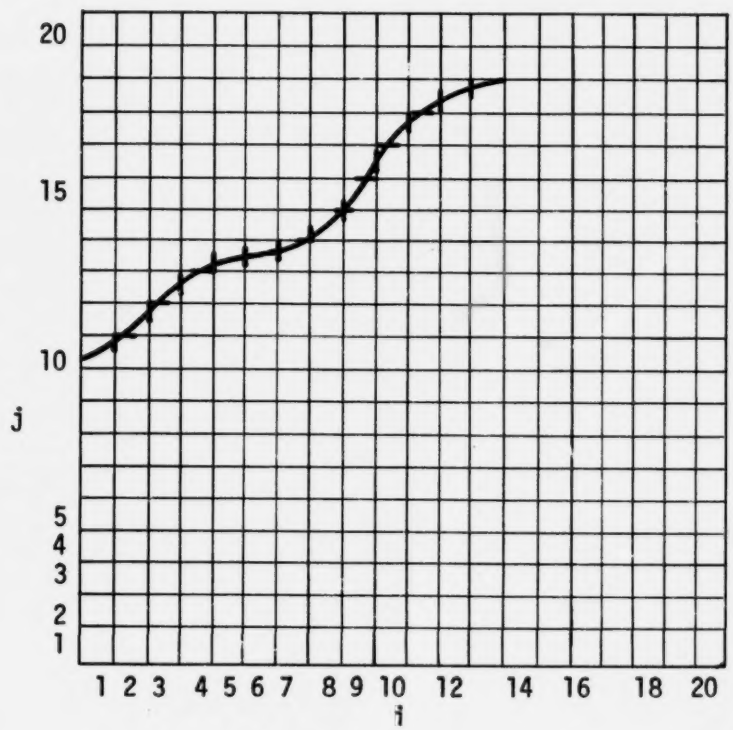

Fig. 7. Trajectory and grid crossing points.

as illustrated in Fig. 7, where horizontal and vertical lines represent the crossing points. It is now possible to determine from the crossing points and the mean wind speed how long the air parcel in question is being affected by the sources in a given grid square. The logical and arithmetical procedures used to convert the description of the trajectory from the initially computed series of points (π,k) to a description in terms of intersections with the grid are most conveniently set out in the form of a computer program, and will be found in the flow diagrams and program which accompany this report.

The trajectory is stored as the series of crossing points and the wind speed between successive pairs of crossing points.

6.3 Choice of the Diffusion Parameters

As we have seen, the standard deviations σ_x, σ_y, and σ_z which appear in eqs. (1) and (2) are, strictly speaking, descriptive parameters which vary from occasion to occasion, but the formulae have, of course, no predictive value unless some numerical values are attached to the σ's. The concept of the σ's as functions of travel distance, as proposed by Meade (1960) and Pasquill (1961, 1962) is illustrated in Turner (1968) and Slade (1968). The magnitudes chosen derive in the main from Pasquill's interpolation of the experimental data. In the model six stability categories are considered and the σ's are defined in terms of the following empirical equations, which closely reproduce Turner's curves but are not exactly equivalent to any previous formulations.

Equations of form

$$\ln \sigma = \alpha + \beta \ (\ln x) + \gamma(\ln x)^2 \qquad (10)$$

where x is downwind distance in meters were assumed. The coefficients were determined statistically from data read off the published curves. The coefficients are:

Stability	Vertical			Lateral		
	α	β	γ	α	β	γ
A	1.23090	-.43984	.15842	-1.02935	.97355	-.00702
B	-0.82953	.52251	.03857	-1.55774	1.01215	-.00801
C	-1.76510	.74932	.01334	-1.89130	.98147	-.00495
D	-2.61432	.91491	-.00557	-2.44760	1.01255	-.00670
E	-3.70065	1.25914	-.04205	-2.66891	.99002	-.00515
F	-4.19033	1.29181	-.04535	-3.06583	.98858	-.00504

The effective distance is computed as set out in Section 5.2 and 5.4, incorporating the time or distance correction for finite grid size. As explained in Section 5.5, the stability category used is that appropriate to the time at the receptor, (i.e., the time at which concentrations are being calculated).

6.4 The Gaussian Weighting Factors

In Section 5.3, we discussed the rationale of the replacement of the continuous Gaussian distribution by sets of $(2n + 1)^2$ weighting factors. Fig. 4 illustrates a 9-square array, where the factors A, B and C are computed by integration of the Gaussian distribution according to the following scheme.

$$A(s) = \frac{1}{2 \pi s^2} \int_{-1/2}^{1/2} d\upsilon \int_{-1/2}^{1/2} d\xi \exp - \frac{\xi^2 + \upsilon^2}{2 s^2}$$

$$B(s) = \frac{1}{2\pi s^2} \int_{-1/2}^{1/2} d\upsilon \int_{-\infty}^{-1/2} d\xi \exp - \frac{\xi^2 + \upsilon^2}{2 s^2}$$

$$C(s) = \frac{1}{2\pi s^2} \int_{-\infty}^{-1/2} d\upsilon \int_{-\infty}^{-1/2} d\xi \exp - \frac{\xi^2 + \upsilon^2}{2 s^2} \qquad (11)$$

$$A + 4B + 4C = 1$$

All lengths are expressed in terms of the grid square side a. Then

$$(x - \bar{u}t) = a\,\xi,\ y = a\,\upsilon,\ \sigma = as$$

and it is assumed $\sigma_x = \sigma_y = \sigma$. In Fig. 2 the concentration at R_1 at ground level due to source emission rate $Q(S_1)$ at position S_1 is given by

$$\chi = Q(S_1) \frac{d}{\bar{u}} \cdot A \cdot \frac{1}{(2\pi)^{1/2}\sigma_z} \qquad (12)$$

where $d/\bar{u}$ represents the distance across the grid square from (η, ζ) to (μ, ν) in Fig. 3 divided by the mean wind speed in that square.

In the application of the model to the Toronto area, a 25-grid square approximation to the Gaussian distribution is proposed. The weighting factors attributed to the squares of this grid, are derived from tabulated values of the bivariate Gaussian distribution.

$$Pr = \frac{1}{2\pi s^2} \int d\upsilon \int d\xi \exp - \frac{\xi^2 + \upsilon^2}{2 s^2}$$

$$w(5) = Pr(\xi>2/s,\ \upsilon>2/s)$$
$$w(4) = Pr(\xi>1/s,\ \upsilon>2/s) - w(5)$$
$$w(3) = Pr(\xi>1/s,\ \upsilon>1/s) - [2\,w(4) + w(5)]$$
$$w(2) = Pr(\xi>0,\ \upsilon>2/s) - [2\,(w(4) + w(5))]$$
$$w(1) = Pr(\xi>0,\ \upsilon>1/s) - [(w(2) + 2\,w(3) + 4\,w(4) + 2\,w(5))]$$
$$w(0) = 1 - [4\,(w(1) + w(2) + w(3) + 2\,w(4) + w(5))]$$

The weights corresponding to six values of s are shown in Table 1.

Table 1

Weights applied to area sources to account for horizontal diffusion

	s						
	0	0.5	0.75	1.0	1.25	1.5	1.75
w_o	1.0	.911072	.650280	.466060	.332108	.244572	.186876
w_1	0	.021686	.075540	.092782	.090510	.079758	.067622
w_2	0	.000028	.002520	.015532	.031580	.045228	.055086
w_3	0	.000516	.008490	.018471	.024666	.026011	.024469
w_4	0	.000001	.000429	.003091	.008607	.014718	.019933
w_5	0	0	.000022	.000518	.003003	.008364	.016238

6.5 The Treatment of Vertical Diffusion

Eq. (4) contains two implied assumptions concerning vertical diffusion. The first is that contaminant is not absorbed at the surface. The general validity of this assumption is doubtful, but it is standard practice to make it, and in the absence of specific information concerning the actual

pollutants considered in the model the assumption is retained. Some adjustment for absorption at the surface may be included in the empirical determination of the half-life in the exponential decay term, during 'calibration' of the model (Section 6.7). The second assumption of eq. (4) is that diffusion in the vertical can be characterized by the single parameter $\sigma_z(x)$, i.e., that the stability category as measured at ground level is a sufficient description of vertical diffusion. This is rarely so and a most important set of cases can be characterized by imposing a fixed 'lid' to diffusion at a 'mixing height' H. Thus, a common physical situation is that turbulence scales are determined by ground level stability until they grow large enough to be damped by an elevated inversion. Further growth is then limited if the inversion is strong enough. Various methods have been used to accommodate this fact. Fortak (1970) for example, replaces the Gaussian term in σ_z by a different analytical expression involving σ_z and H which yields computed concentrations asymptotic to zero at height H. Turner (1968) advocates the use of the Gaussian function until $\sigma_z(x) = 0.47H$, uniform concentration in the vertical at twice this distance, and linear interpolation in between. Turner's method is adopted in the TRC model. Quoting Turner - "The dispersion computation can be modified for this situation by considering the height of the base of the stable layer, L. At a height 2.15 σ_z above the plume centerline the concentration is one-tenth the plume centerline concentration at the same distance. When one-tenth the plume centerline concentration extends to the stable layer, at height L, it is reasonable to assume that the distribution starts being affected by the 'lid'." The following method is suggested to take care of this situation. Allow σ_z to increase with distance to a value

of L/2.15 or 0.47 L. At this distance x_L, the plume is assumed to have a Gaussian distribution in the vertical. Assume that by the time the plume travels twice this far, $2x_L$, the plume has become uniformly distributed between the earth's surface and the height L, i.e., concentration does not vary with height. For the distances greater than $2x_L$, the concentration for any height between the ground and L can be calculated from:

$$\chi = \frac{Q}{\sqrt{2\pi}\ \sigma_y\ L\ \bar{u}} \quad \exp - \left(\frac{y^2}{2\ \sigma_y^2} \right) \tag{13}$$

for any z from 0 to L, for $x > 2\ x_L$; x_L is where $\sigma_z = 0.47L$. Note that this equation assumes normal or Gaussian distribution of the plume only in the horizontal plane. The same result can be obtained from the following equation where σ_{zL} is an effective dispersion parameter because $\sqrt{2\pi}\ L = 2.5066L$ and $0.8\ \pi\ L = 2.51L$.

$$\chi = \frac{Q}{\pi\ \sigma_y\ \sigma_{zL}\ \bar{u}} \quad \exp - \left(\frac{y^2}{2\ \sigma_y^2} \right) \tag{14}$$

for any z from 0 to L, for $x > 2x_L$; x_L is where $\sigma_z = 0.47L$. The value of $\sigma_{zL} = 0.8\ L$.

Application of Turner's method to the major point sources is straightforward; the formula applies directly. For the area sources the distance x_L in Turner's formulation must be measured backwards from the receptor point; for grid squares more distant than $2x_L$ from the receptor the constant factor $\sigma_z = 0.8L$ applies.

6.6 Calibration of the Model - Flux across the Boundary

There are two aspects in which the model is not self-contained and requires empirical calibration. These concern sources outside the grid boundaries and the half-life characterizing the apparent decay or loss of material.

Flux of material from the greater New York City area was a major problem in the application of the model to Connecticut. The late Professor Ben Davidson advised that 10^6 tons/year of SO_2 were emitted in New York City and for distant receptors could be considered to be released along a line 35 km long centered at the Battery orientated perpendicular to the mean wind direction. This source strength was further broken down into 50% basic and 50% distributed by degree days. The standard continuous line source Gaussian equation was used to calculate the concentration of SO_2 at the border of the Connecticut grid for the appropriate wind directions. One of 25 verification periods of observations (Section 7) was used to confirm these initial estimates of boundary concentration, and at the same time establish a decay constant for SO_2 of the form discussed in Section 5.7 (see also Section 6.7). The validity of the new estimates was supported by subsequent verification data.

Sources from other regions were not known. It was assumed that land use in New York (outside New York City), Massachusetts and Rhode Island is similar to that in Connecticut and that, apart from that originating in the New York City area, there is no net import or export of pollutant from the model area. Using the model, a calculation was made of the concentration at the eastern border of the grid from Connecticut sources for a west wind. The simulated pattern is shown in Fig. 8. The mean con-

centration from this calculation was used as the concentration at all points on the boundary with an inward-flowing wind component, other than any affected by the New York City source.

Ground level mobile monitors and vertical soundings with airborne SO_2 sampling equipment confirmed the general validity of these assumptions, including the "raggedness" of the concentration profile. In an application of the model, direct measurements of contributions of sources beyond the grid boundary could be incorporated if available.

6.7 Calibration of the Model - Decay of Pollutant

When the flux from New York City, predicted by the line source model with no allowance for loss of pollutant, was compared with that measured near the model boundary, it was apparent that either diffusion was much more rapid than anticipated or that a removal process was active. Measured vertical profiles of SO_2 were consistent with the assumed diffusion conditions so the discrepancy was considered to be the result of a removal process. The same feature was noted in the calculation of the flux of material out of Connecticut. The only way in which a removal process can be incorporated into a Gaussian model is set out in Section 5.7. Turner (1964) found that in St. Louis, Mo., the removal process for SO_2 could be approximated by a decay characterized by a "half-life" of a few hours. A three-hour half-life was employed on the "calibration" test data and yielded satisfactory results. This half-life was adopted for all subsequent tests. It is known that SO_2 does oxidize to SO_3 in the atmosphere and time scales for the reaction have been measured or inferred from several sets of observations and from experiments. Although a wide range

of results has been found, a three-hour half-life is well in the middle of this range.

6.8 Height of Source

Eqs. (1) and (2) contain the parameter H, the effective source height. There is considerable literature on the evaluation of this parameter for industrial stacks where the emitted gases possess buoyancy and upward momentum, but there is no theoretically satisfactory and generally accepted procedure for determining an "effective height" for insertion into the Gaussian formulae. There are several empirical procedures: that adopted for major point sources in the Connecticut application of the TRC model was to multiply the actual stack height by the factor 1.5. The minor (area averaged) sources were assumed to be at a height of 10 m. In the Toronto application the empirical formula by Stumke (1963)

$$H = h + \Delta H = h + 1.5 \frac{w}{\bar{u}} D + 65 \frac{D^{3/2}}{\bar{u}} \frac{\Delta T^{1/4}}{T_s} \qquad (15)$$

was used for major sources where w is exit velocity of the stack gas, D is stack diameter, ΔT is the excess of stack gas temperature over ambient and T_s is the stack gas temperature. Temperatures are in degrees Kelvin, velocities in m sec^{-1}, and distances in meters. Note that the formula is not dimensionally self-consistent.

6.9 Summary of Operating Procedures - Flow of Computation for One Receptor

We assume all pertinent information has been read and the program is

ready to operate on the input data at this point. The first receptor point is selected and its i, j coordinates noted. The following sequence of events occurs (with reference to subroutine names in the flow diagrams in the Appendix).

1. Enter Trajectory (TRAJEC)
   a) Load the wind field stream values for the current prediction period.
   b) Calculate the trajectory to the border of the grid, incorporating new wind field stream values if required.
   c) Calculate the trajectory grid crossing points to the border and the associated wind speed for each segment.
2. Enter Concentration (CONC)
   a) Calculate the distances, from the lengths of the line segments, from the receptor to source grid points.
   b) Enter vertical distribution routine (SIGZZ) to obtain the appropriate σ_z value.
   c) Enter horizontal distribution routine (SIGYY) to obtain the appropriate σ_y value.
   d) Enter QWT routine to weight the central source square, being used together with its eight neighbors. Each of the nine sources is weighed according to the value of σ_y.
   e) Calculate the concentration from these sources and

add to those for previous line segments.

f) Go back to 2 a) and repeat until all line segments have been accounted for and summed.

g) Enter the Boundary Correction Routine (BOUND) to calculate the concentration to be added to account for material emitted outside of the specific grid area.

h) Calculate the contribution from point sources (QPTSRC) that may affect this receptor point. This requires use of subroutines FILET (to identify points within 3 grid squares of the trajectory line) and SIGYY and SIGZZ (for the appropriate diffusion coefficients).

i) Add the concentrations from area sources, point sources and boundary sources to obtain the total pollutant concentration.

3. Select the next receptor point and repeat from Step 1 until list of receptor points is exhausted.

7.0 References

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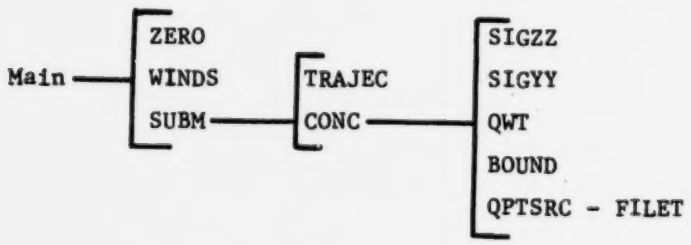
APPENDIX

Flow Diagrams

Interrelational Structure of the Subroutines
in the
TRC Regional Air Quality Simulation Model



FORTRAN MODULE (LIST1,NAMSO)

CARD NO **** CONTENTS ****

```
      C
      C
      C MAIN MODIFIED TO HANDLE MULTIPLE PERIOD PREDICTIONS
      C
      C  COMMON FROM SUBROUTINES
           COMMON ALS(247),INIJ(233),ITRNON(50),JTO(50),II(200),
          XJJ(200),HI(20),IST(20),ALS(5),X(200),Y(200),VBAR(200),P(200),
          XOL(200),CHI,ITOT,TO,N,T,DT,GS,NMLS,XMIN,XMAX,YMIN,YMAX,IBUG,DG,DS,
          XSIGZJ,SIGZ,SIGDT,NG,L,TJ,I,J,U,V,DX,DY,NL,IR,KL,M,LL,KK,MM,S,TL,F,
          XA,A,TT,D,SIGV,DL,SIGZLN,HT,T1,DT,IT3,PI,K,LND,C,ICHI,ZO,JST(20),
          XPCHI,IPRINT,MAXP,QPT(50),HPT(50),NGRIDS,MJ
           COMMON/COM01/ ID4,ID5
           COMMON/COM02/ Q(105,75)
           DIMENSION RMEM2(100,12),RMEM(100),TITL(20)
           DIMENSION IJC(200,2)
           EQUIVALENCE(IJC(1,1),II(1))
           DEFINE FILE 4(140,900,U,ID4)
           DEFINE FILE 5(140,930,U,ID5)
      100 FORMAT(20A4)
      101 FORMAT (2014)                                                  6460
      102 FORMAT (8F10.0)                                                6470
      104 FORMAT (16F5.0)                                                6490
      105 FORMAT (2I5,F5.0,E12.4)                                        6500
      109 FORMAT(I5,12F5.3)
      110 FORMAT(I5,12F5.1)
      400 FORMAT(4I5)
          CALL ZERO(INIJ,200)
          CALL WINDS
          READ(1,100)      TITL
C  TITL=THE TITLE TO BE USED FOR THE PUNCHED CARDS
          READ(1,400)    MMM,KPOL
C   MMM REPRESENTS THE NUMBER OF TIMES THE MODEL IS TO BE RUN.(MAX.=12)
C   KPOL=1 FOR SO2 PREDICTIONS, =2 FOR PARTICULATE PREDICTIONS
          READ(1,102)     ZO,QPT(50)                                   6180
C  ZO=DECAY TIME FOR DEPOSITION(HOURS)
C   QPT(50)  REPRESENTS THE AMPLITUDE FACTOR FOR THE BOUNDARY CONTRIBUTIONS
          READ (1,102) TO,T,DT,GS,XMIN,XMAX,YMIN,YMAX                   6190
C  TO= INITIAL TIME FOR VOLUME SOURCE CORRECTION IN MINUTES            6195
C  T = TIME BETWEEN CHANGES OF SOURCE AND WIND FIELDS IN HOURS         6200
C  DT= TIME STEP FOR ITERATIONS OF WIND TRAJECTORY IN MINUTES          6210
C  GS= GRID SPACING IN METERS                                          6220
C  XMIN, XMAX, YMIN, YMAX = LOW AND HIGH VALUES FOR SOURCE DATA        6230
C   STANDARD VALUES ARE 2,104 AND 2,74                                 6240
          READ(1,403)     NSP
C   NSP=NO. OF POINTS OF INTEREST
          READ (1,101) ((IJC(I,J),J=1,2),I=1,NSP)                     6250
C  IJC = I,J PAIRS OF COORDINATES OF POINTS OF INTEREST                6260
          READ(1,104)     HLS(1)
C   NMLS=1     AT THIS TIME
C  HLS= SOURCE HEIGHT AVERAGE FOR A LAYER IN METERS                    6350
          READ (1,101) MAXP                                            6360
C  MAXP = NO. OF POINT SOURCE COORDINATES                              6370
          DO 1 I=1,MAXP                                                6380
          J=2*I                                                        6390
          K=J-1                                                        6400
        1 READ (1,105) INIJ(K),INIJ(J),HPT(I),QPT(I)                  6410
C  I,J PAIR OF COORDINATES FOR POINT SOURCES                           6420
C  HPT = HEIGHT OF POINT SOURCE ABOVE GROUND IN METERS                 6430
C  QPT = SOURCE STRENGTH OF POINT SOURCE AT I,J  ONE PER CARD          6440
          ID4=1
          DO 20  LP=1,12
          READ(10)    Q
          WRITE(4'ID4)  Q
       20 CONTINUE
          DO 21   LP=1,3
          WRITE(4'ID4)  Q
       21 CONTINUE
          REWIND 10
          READ(1,105)  IBUG,IPRINT
          CON1=ZO
          CON2=TO
          CON3=T
          CON4=DT
          DO 200   LPMAIN=1,MMM
          READ(1,105)  IT4
          CALL SUBM(RMEM,NSP)
          Z1=CON1
          T3=CON2
          T=CON3
          DT=CON4
          DO 50   LIL=1,NSP
       50 RMEM2(LIL,LPMAIN)=RMEM(LIL)
      200 CONTINUE
          WRITE(12,100)  TITL
          GO TO (75,76),   KPOL
       75 DO 77    NNL=1,NSP
       77 WRITE(12,109)  NNL,(RMEM2(NNL,I),I=1,MMM)
          GO TO 87
       76 DO 79    NNL=1,NSP
       79 WRITE(12,110)  NNL,(RMEM2(NNL,I),I=1,MMM)
       87 STOP
          END
```

CHART TITLE - PROCEDURES

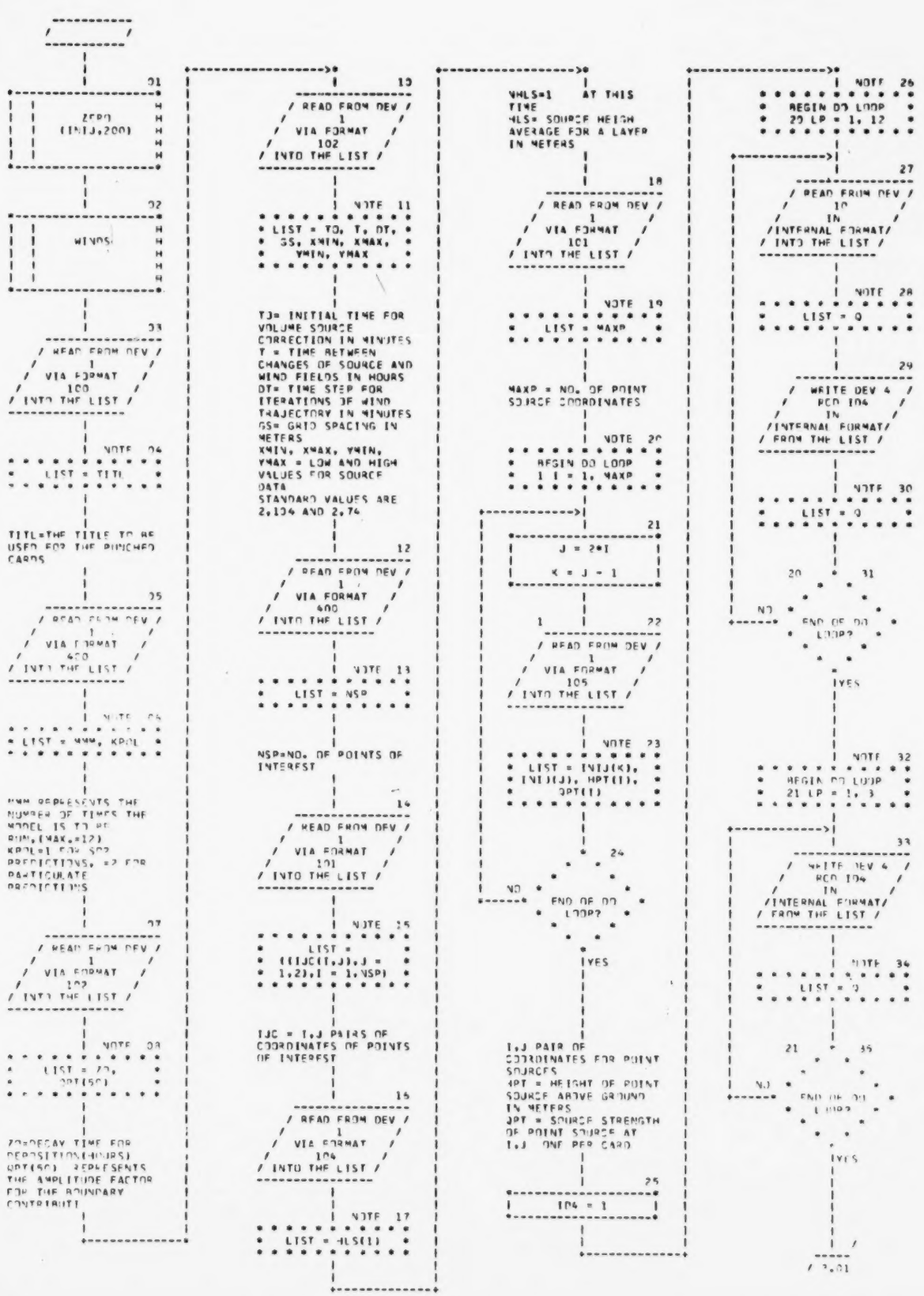
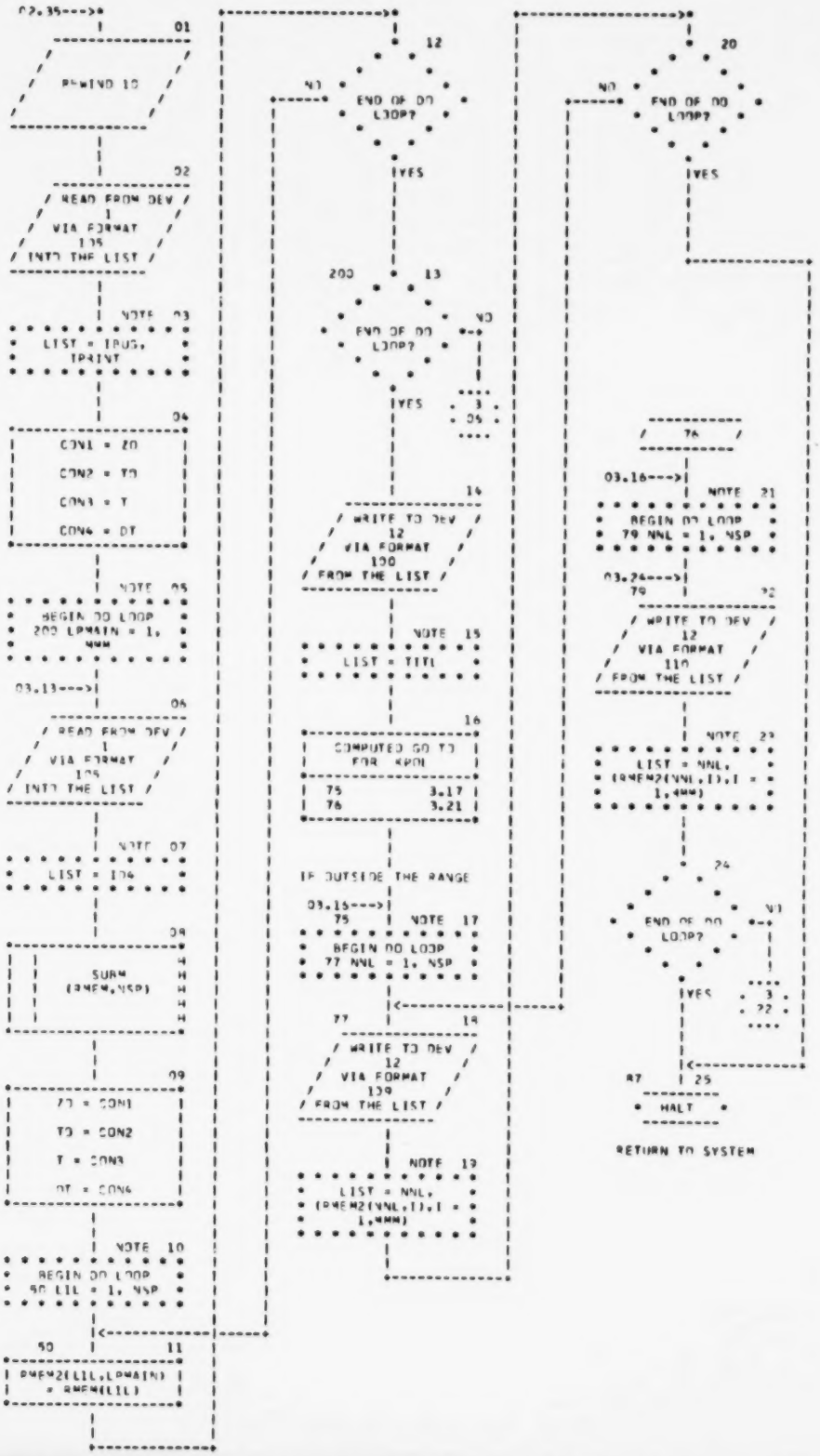

01
ZERO (INIJ,200)
02
WINDS
03
READ FROM DEV 1 VIA FORMAT 100 INTO THE LIST
NOTE 04
LIST = TITL
TITL=THE TITLE TO BE USED FOR THE PUNCHED CARDS
05
READ FROM DEV 1 VIA FORMAT 400 INTO THE LIST
NOTE 06
LIST = MMM, KPOL
MMM REPRESENTS THE NUMBER OF TIMES THE MODEL IS TO BE RUN,(MAX.=12)
KPOL=1 FOR SO2 PREDICTIONS, =2 FOR PARTICULATE PREDICTIONS
07
READ FROM DEV 1 VIA FORMAT 102 INTO THE LIST
NOTE 08
LIST = ZZ, QPT(SC)
ZZ=DECAY TIME FOR DEPOSITION(HOURS) QPT(SC) REPRESENTS THE AMPLITUDE FACTOR FOR THE BOUNDARY CONTRIBUTI
09
READ FROM DEV 1 VIA FORMAT 102 INTO THE LIST
NOTE 11
LIST = TO, T, DT, GS, XMIN, XMAX, YMIN, YMAX
TO= INITIAL TIME FOR VOLUME SOURCE CORRECTION IN MINUTES
T = TIME BETWEEN CHANGES OF SOURCE AND WIND FIELDS IN HOURS
DT= TIME STEP FOR ITERATIONS OF WIND TRAJECTORY IN MINUTES
GS= GRID SPACING IN METERS
XMIN, XMAX, YMIN, YMAX = LOW AND HIGH VALUES FOR SOURCE DATA
STANDARD VALUES ARE 2,104 AND 2,74
12
READ FROM DEV 1 VIA FORMAT 400 INTO THE LIST
NOTE 13
LIST = NSP
NSP=NO. OF POINTS OF INTEREST
14
READ FROM DEV 1 VIA FORMAT 101 INTO THE LIST
NOTE 15
LIST = (((IJC(I,J),J = 1,2),I = 1,NSP)
IJC = I,J PAIRS OF COORDINATES OF POINTS OF INTEREST
16
READ FROM DEV 1 VIA FORMAT 104 INTO THE LIST
NOTE 17
LIST = HLS(I)
NHLS=1 AT THIS TIME
HLS= SOURCE HEIGH AVERAGE FOR A LAYER IN METERS
18
READ FROM DEV 1 VIA FORMAT 101 INTO THE LIST
NOTE 19
LIST = MAXP
MAXP = NO. OF POINT SOURCE COORDINATES
NOTE 20
BEGIN DO LOOP I I = 1, MAXP
21
J = 2*I
K = J - 1
22
READ FROM DEV 1 VIA FORMAT 105 INTO THE LIST
NOTE 23
LIST = INIJ(K), INIJ(J), HPT(I), QPT(I)
24
NO
END OF DO LOOP?
YES
I,J PAIR OF COORDINATES FOR POINT SOURCES
HPT = HEIGHT OF POINT SOURCE ABOVE GROUND IN METERS
QPT = SOURCE STRENGTH OF POINT SOURCE AT I,J ONE PER CARD
25
IO4 = 1
NOTE 26
BEGIN DO LOOP 25 LP = 1, 12
27
READ FROM DEV 10 IN /INTERNAL FORMAT/ INTO THE LIST
NOTE 28
LIST = Q
29
WRITE DEV 4 RCD IO4 IN /INTERNAL FORMAT/ FROM THE LIST
NOTE 30
LIST = Q
20
31
NO
END OF DO LOOP?
YES
NOTE 32
BEGIN DO LOOP 21 LP = 1, 3
33
WRITE DEV 4 RCD IO4 IN /INTERNAL FORMAT/ FROM THE LIST
NOTE 34
LIST = Q
21
35
NO
END OF DO LOOP?
YES
2.01

CHART TITLE - PROCEDURES



CONTAIN MODULE (LIST1,MAMSD)

**** CONTENTS ****

SUBROUTINE SUBMERMER,NSP)
C COMMON FROM SUBROUTINES
COMMON ALS(2747),IME(6700),ITRNON(50),JTD(50),III(200),
XJJ(200),HI(20),IST(20),JST(20),KI(2300),Y(200),YMAX(200),PI(200),
XDL(200),CHI,ITD1,TD,N,T,DT,GS,NMLS,XMIN,XMAX,YMIN,YMAX,IAUG,DG,DS,
XSIGZ3,SIGF,SIGDT,NG,L,T2,I,J,U,V,DX,DY,NL,IX,KL,M,LL,KK,MM,S,TL,P,
XA,B,TT,D,SIGV,DL,SIGZL,WT,TI,QT,ITD,PI,X,LN3,C,NCHI,Z0,JST(20),
XPCHI,IPRINT,MAXP,OPT(50),APT(50),NGRIDS,MJ
COMMON/COM01/ IO4,IO5
DIMENSION RMEM(100)
DIMENSION IJC(200,2),TITL(20)
READ (1,100) TITL
NMLS=1
NGRIDS=15-IO4/9
NMIST=NGRIDS
C NMLS=NO. OF LAYERS OF SOURCE DATA
C NMIST=NO. OF DIFFERENT STABILITY PARAMETERS, NGRIDS= NO OF GRIDS OF
C SOURCE OR WIND DATA
C IT3= LOGICAL TAPE UNIT CONTAINING WIND DATA
C IT1= LOGICAL TAPE UNIT CONTAINING SOURCE DATA
C IAUG=1 FOR CHECKOUT, =0 FOR PRODUCTION
C IPRINT=1 FOR PRINTING CONTRIBUTION OF POINT SOURCES AND BOUNDARY FLUX
READ(1,139) HI(1)
C HI= HEIGHT OF INVERSION LAYER BY STABILITY PERIOD IN METERS, USE
C LARGE VALUE FOR NO INVERSION (1.0E+10)
READ(1,131) IST(1)
READ(1,101) JST(1)
DO 110 LPL=2,NMIST
HI(LPL)=HI(1)
IST(LPL)=IST(1)
110 JST(LPL)=JST(1)
C IST = LATERAL STABILITY CONTROL RANGE 1 TO 5 1 IS VERY UNSTABLE
C JST = VERTICAL STABILITY CONTROL RANGE 1 TO 5 5 IS VERY STABLE
130 FORMAT (2746)
101 FORMAT(2I4)
103 FORMAT (6E12.6)
106 FORMAT (1H1,2746/38H0 STARTING POINT CONCENTRATION /
X 92H NO. I J CHI,* #ENT SOURCE*,/)
107 FORMAT (16,2I6X,I3),5X,1PE12.4,5X,2F10.0)
TD=60.*TO
DT=60.*DT
T=3600.*T
IREZ(3) 9,9,10
10 Z3=-.693/(Z0*3600.)
9 DG=DT/GS
DS=.5/GS
SIGZ3=1.
PI=2.50662
DO 108 I=1,247
108 ALS(I)=0.0
WRITE (3,104) TITL
CONSTA=104
DO 5 NL=1,NSP
I=III(NL)
J=JJJ(NL)
CHI=0.
DO 6 LN0=1,NMLS
104=CONSTA
105=104
CALL TRAJEC(TITL)
TITL(1)=TT/T
CALL CONC(TITL)
TITL(2)=TT/T
6 CONTINUE
WRITE (3,107) NL,III(NL),JJJ(NL),CHI,TITL(1),TITL(2)
RMEM(NL)=CHI
5 CONTINUE
RETURN
END

CHART TITLE - SUBROUTINE SURM(NMEM,NSP)

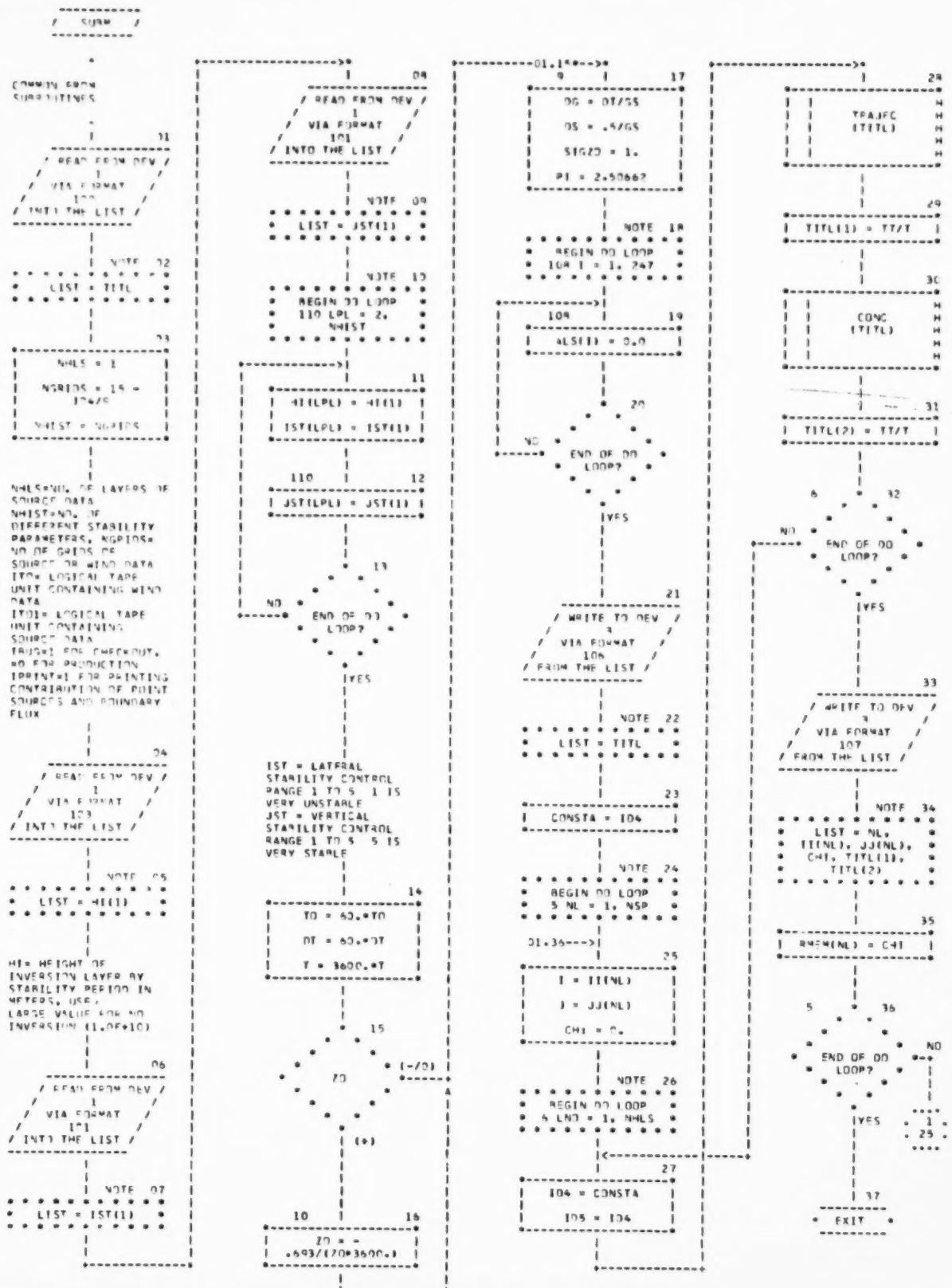


CHART TITLE - SUBROUTINE FILET

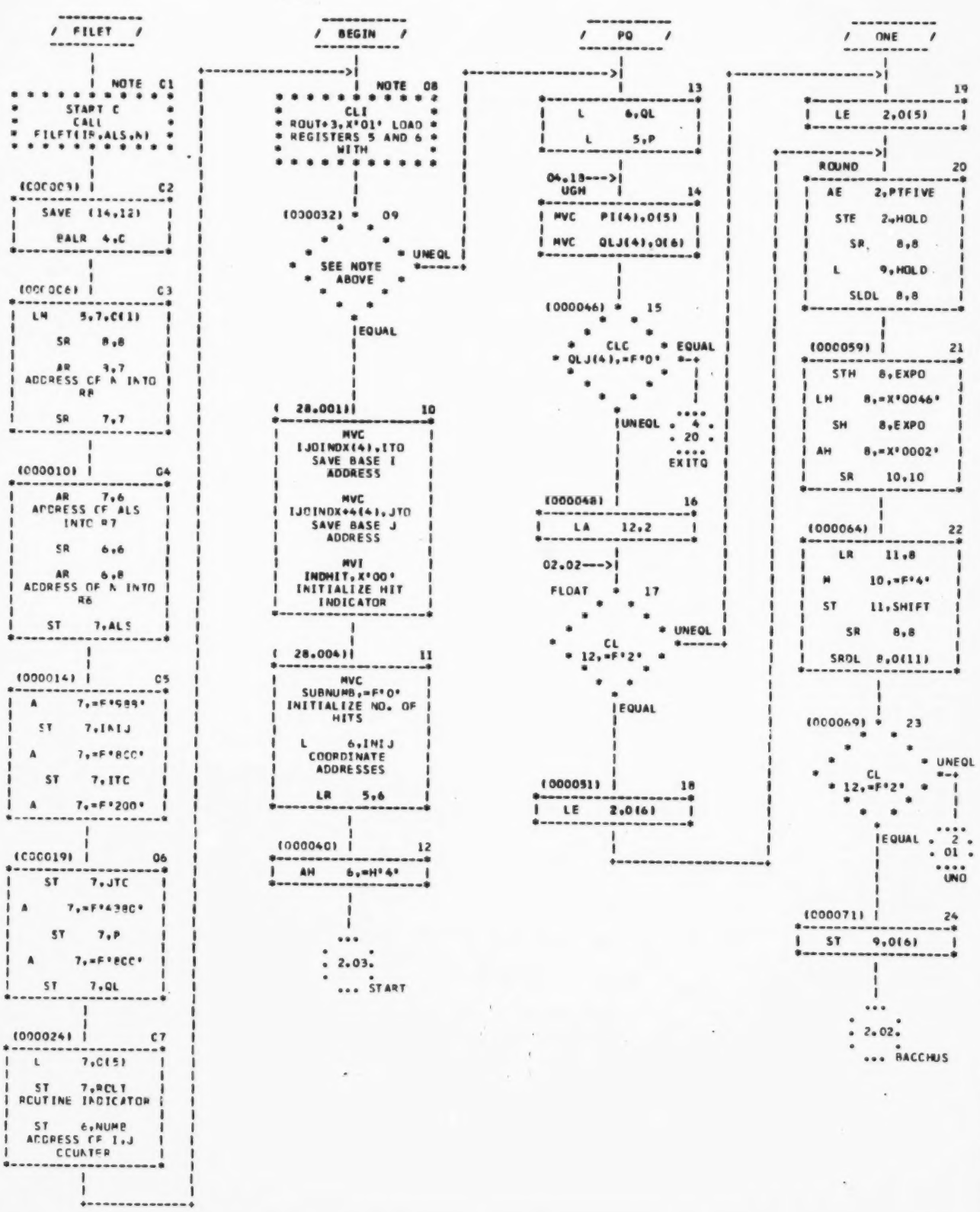


CHART TITLE - SUBROUTINE FILET CONTINUED

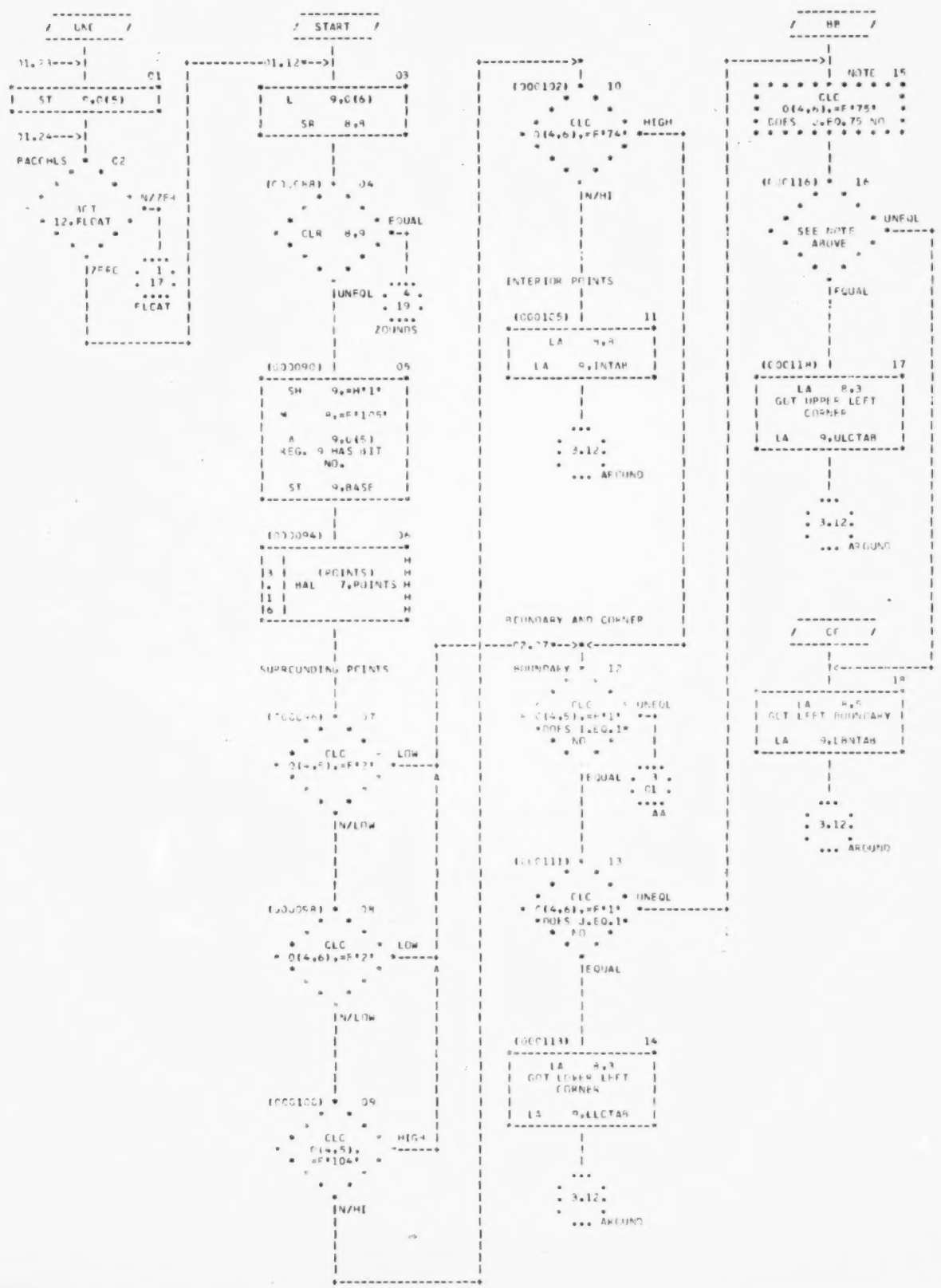


CHART TITLE - SUBROUTINE FILET CONTINUED

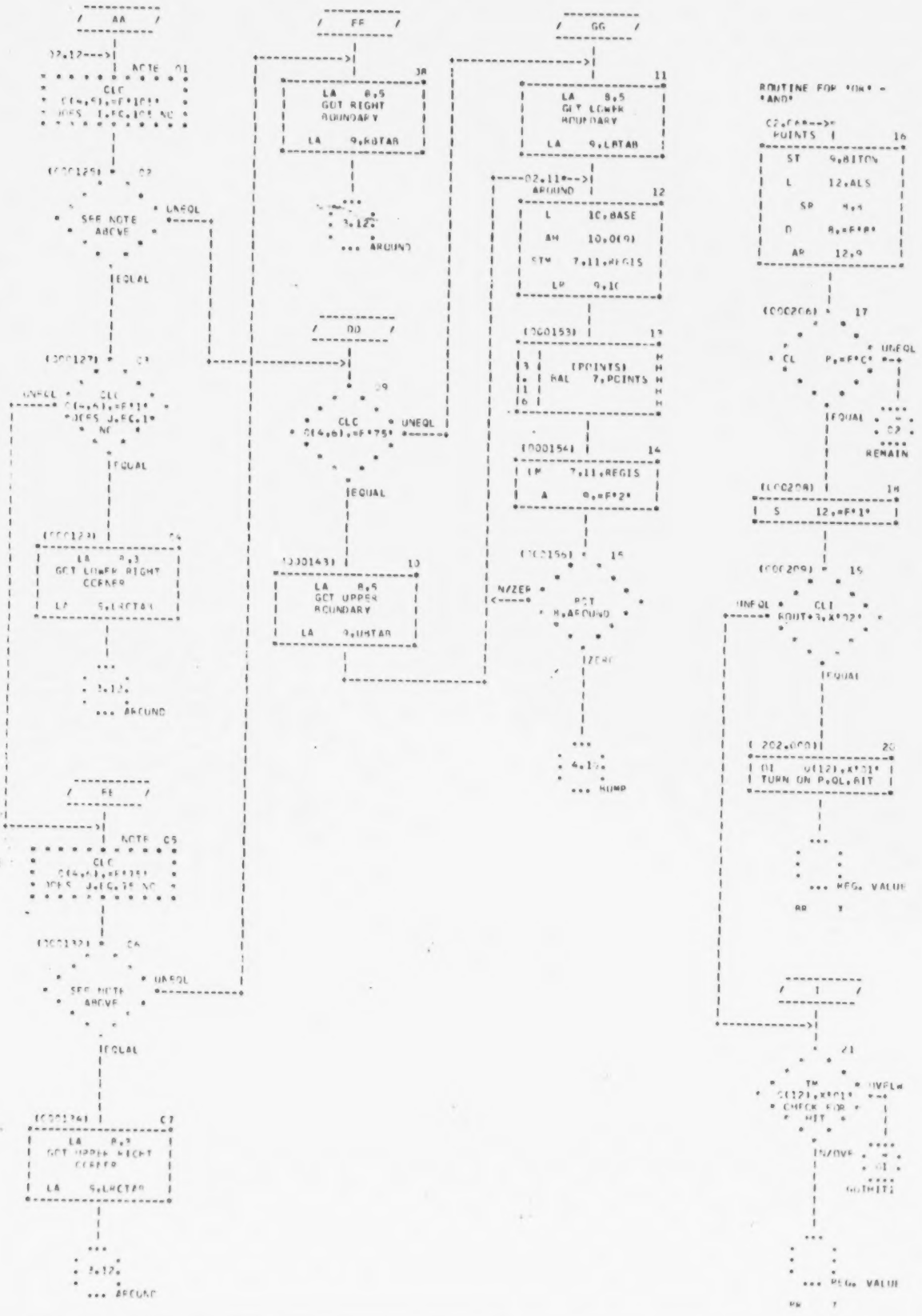
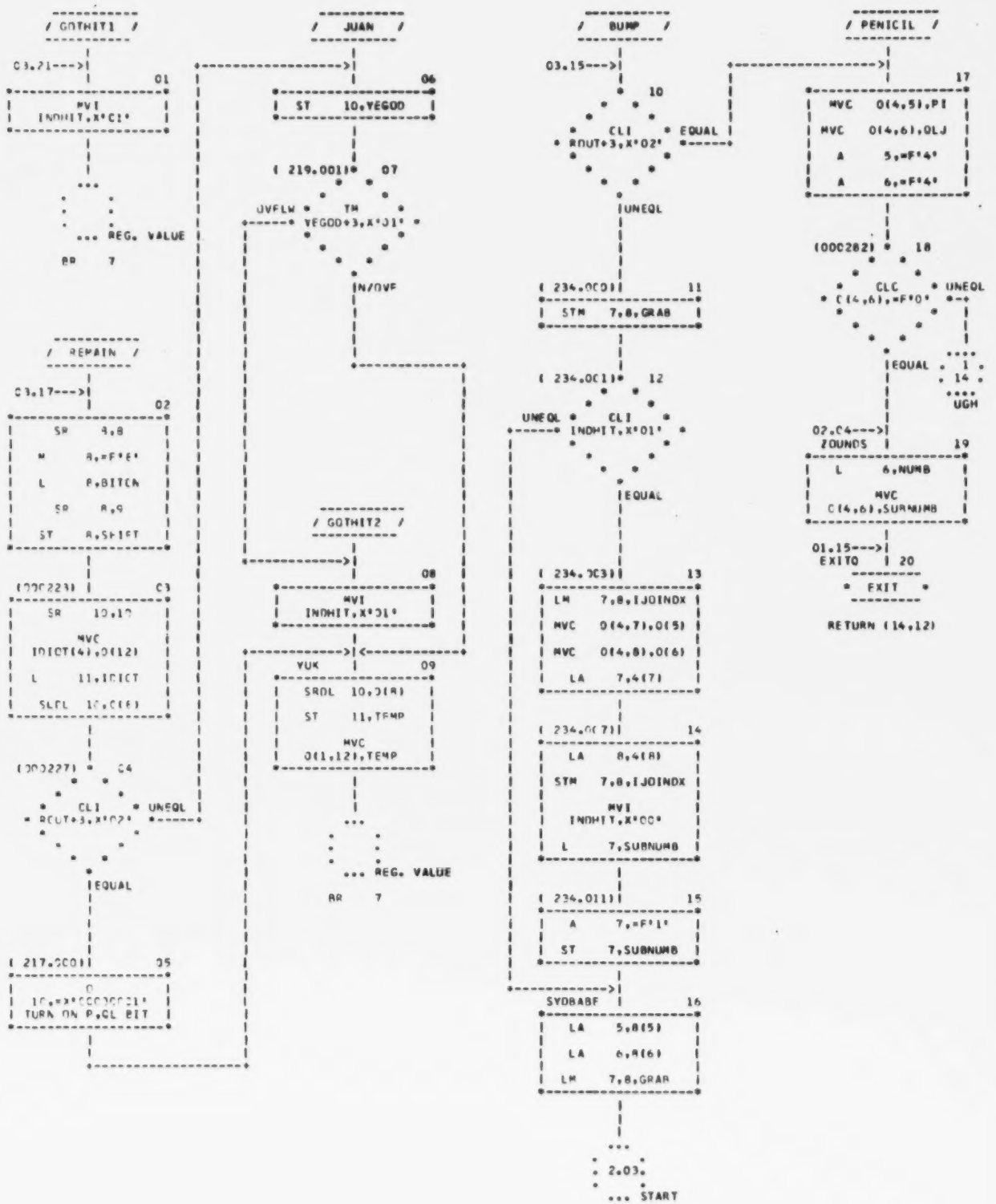


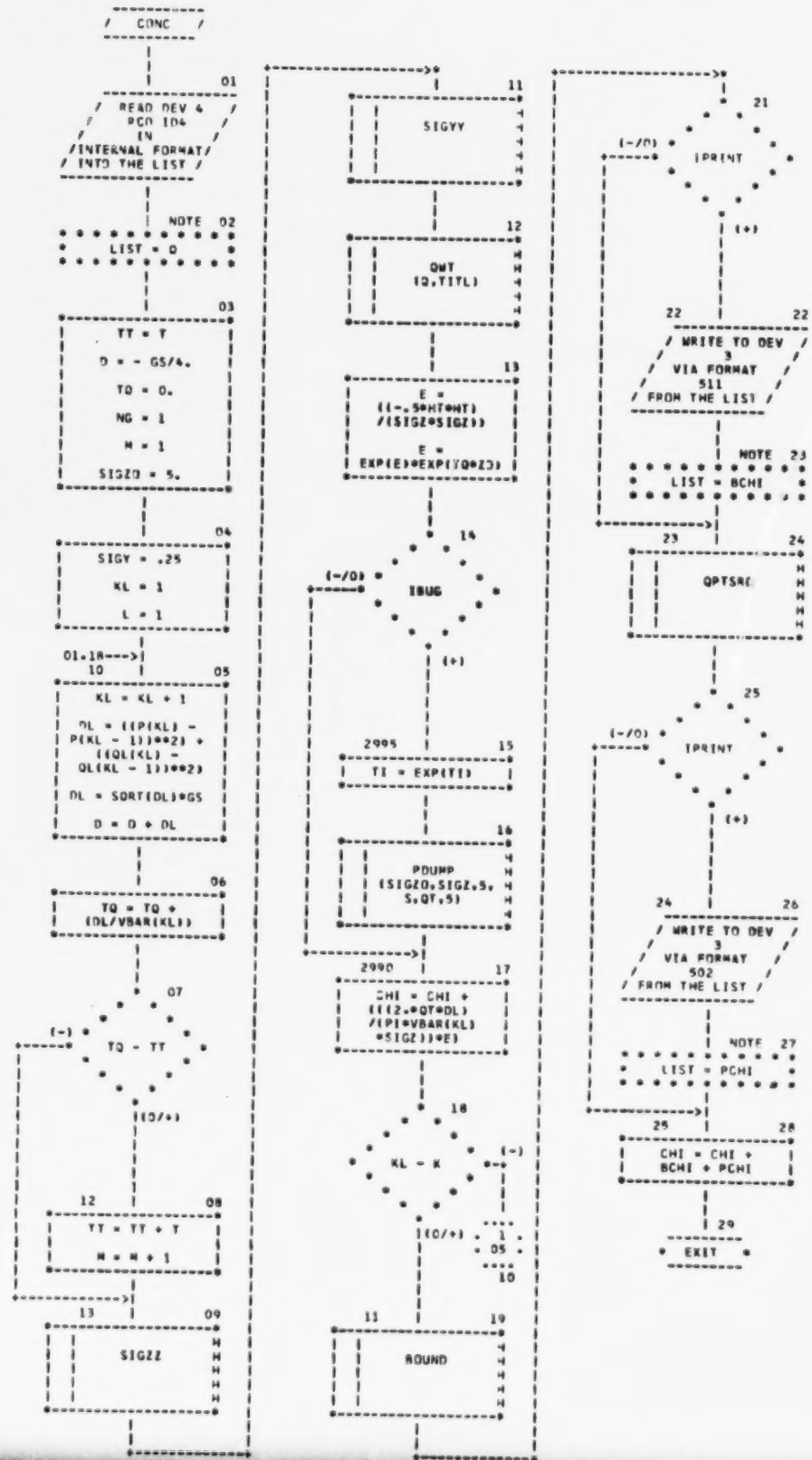
CHART TITLE - SUBROUTINE FILET CONTINUED



FORTRAN MODULE (LIST1,NAMSO)

CARD NO	**** CONTENTS ****	
1	SUBROUTINE CONC(TITL)	
2	COMMON ALS(247),INIJ(200),ITRNON(50),JTO(50),II(200),	
3	XJJ(200),HI(20),IST(20),HLS(5),X(200),Y(200),VBAR(200),P(200),	6020
4	XQL(200),CHI,ITOT,TO,N,T,DT,GS,NHLS,XMIN,XMAX,YMIN,YMAX,IBUG,DS,DS,	
5	XSIGZO,SIGZ,SIGDT,NG,L,TQ,I,J,U,V,DX,DY,NL,IR,KL,M,LL,KK,MM,S,TL,F,	
6	XA,B,TT,D,SIGY,DL,SIGZLN,HT,TI,QT,ITO,PI,K,LNO,C,BCHI,ZO,JST(20),	6050
7	XPCHI,IPRINT,MAXP,QPT(50),HPT(50),NGRIDS,MJ	6060
8	COMMON/COM01/ ID4,ID5	
9	COMMON/COM02/ Q(105,75)	
10	DIMENSION TITL(20)	
11	READ(4'ID4) Q	
12	TT=T	
13	D=-GS/4.	00003430
14	TQ=0.	00003431
15	NG=1	
16	M=1	00003440
17	SIGZO=5.	00003450
18	SIGY=.25	00003460
19	KL=1	00003470
20	L=1	00003480
21	10 KL=KL+1	00003490
22	DL=((P(KL)-P(KL-1))**2)+((QL(KL)-QL(KL-1))**2)	00003500
23	DL=SQRT(DL) * GS	00003510
24	D=D+DL	00003520
25	TQ=TQ+(DL/VBAR(KL))	00003521
26	IF (TQ-TT) 13,12,12	3522
27	12 TT=TT+T	3523
28	M=M+1	3524
29	13 CALL SIGZZ	3530
30	CALL SIGYY	3540
31	CALL QWT (Q,TITL)	3550
32	E=((-.5*HT*HT)/(SIGZ*SIGZ))	00003560
33	E=EXP(E)*EXP(TQ*ZO)	
34	IF(IBUG)2990,2990,2995	00003580
35	2995 TI=EXP(TI)	3581
36	CALL PDUMP (SIGZO,SIGZ,S,S,QT,5)	3590
37	2990 CHI=CHI+(((2.*QT*DL) /(PI*VBAR(KL)*SIGZ))*E)	00003600
38	IF(KL-K)10,11,11	00003610
39	11 CALL BOUND	
40	IF(IPRINT) 23,23,22	3614
41	22 WRITE (3,511) BCHI	3615
42	511 FORMAT (40X,' BOUNDARY CONTRIBUTION = ',1PE13.5)	3616
43	23 CALL QPTSRC	3617
44	IF (IPRINT) 25,25,24	3618
45	24 WRITE (3,502) PCHI	3619
46	502 FORMAT (40X,' POINT SOURCE CONTRIBUTIONS = ',1PE13.5)	3620
47	25 CHI=CHI+BCHI+PCHI	3621
48	RETURN	3622
49	END	00003630

CHART TITLE - SUBROUTINE CONC(TITL)

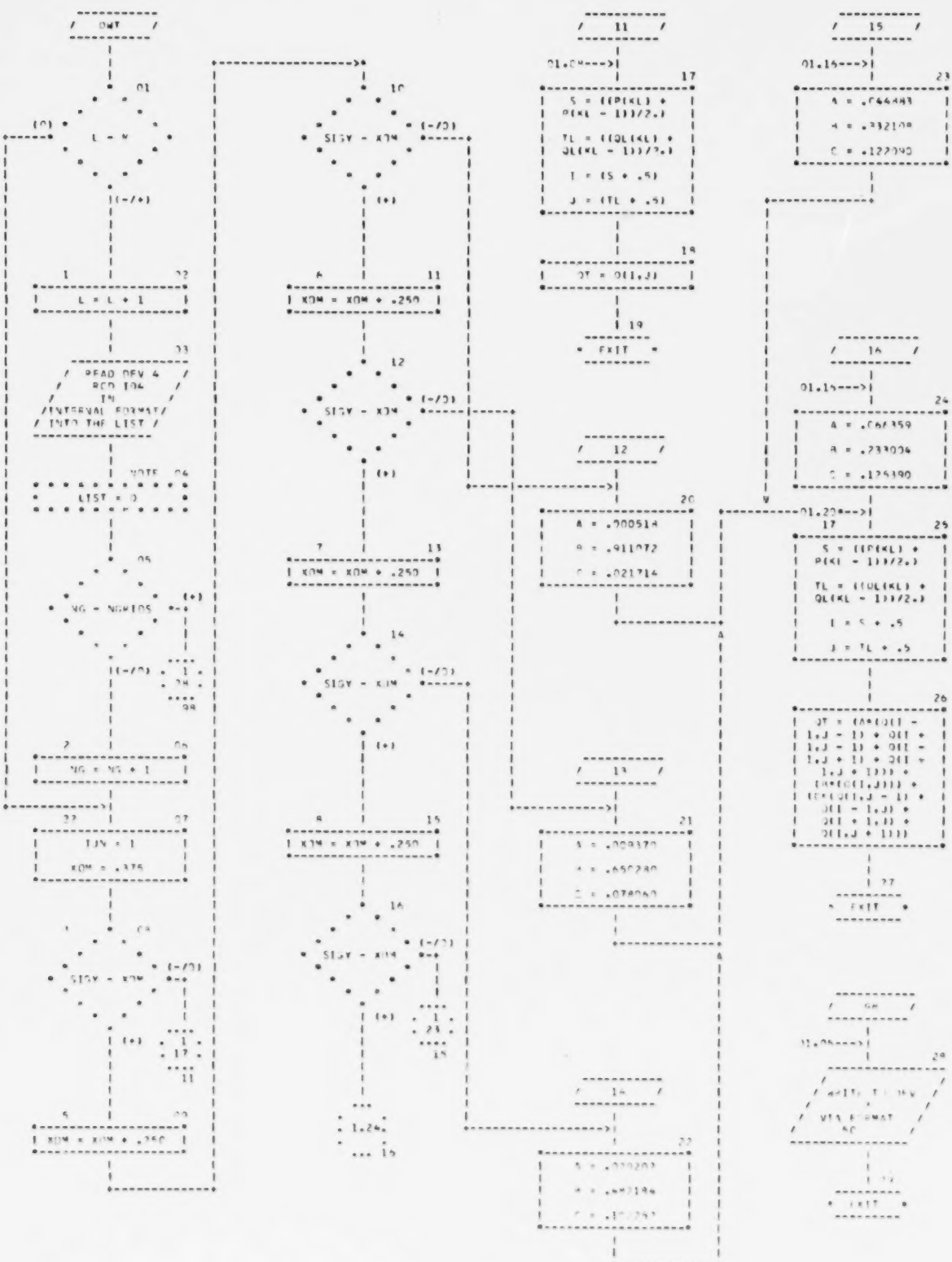


FORTRAN MODULE (LIST1,NAMSQ)

CARD NO **** CONTENTS ****

```
      1              SUBROUTINE QWT (Q,TITL)
      2              COMMON ALS(247),INIJ(200),ITRNON(50),JTO(50),II(200),
      3             XJJ(200),HI(20),IST(20),HLS(5),X(200),Y(200),V9AR(200),P(200),          6020
      4             XQL(200),CHI,ITO1,TO,N,T,DT,GS,NHLS,XMIN,XMAX,YMIN,YMAX,IBUG,DG,DS,
      5             XSIGZJ,SIGZ,SIGDT,NG,L,TQ,I,J,U,V,DX,DY,NL,IR,KL,M,LL,KK,MM,S,TL,F,
      6             XA,B,TT,D,SIGY,DL,SIGZLN,HT,TI,DT,ITO,PI,K,LNO,C,BCHI,ZO,JST(20),       6050
      7             XPCHI,IPRINT,MAXP,QPT(50),HPT(50),NGRIDS,MJ                             6060
      8              COMMON/COMO1/ ID4,ID5
      9              DIMENSION TITL(20),Q(105,75)
     10              IF(L-M)  1,22,1
     11            1 L=L+1
     12              READ(4'ID6)  Q
     13              IF(NG-NGRIDS)  2,2,98
     14            2 NG=NG+1
     15           22 IJN=1
     16              XOM=.375
     17            3 IF(SIGY-XOM)11,11,5
     18            5 XOM=XOM+.250
     19              IF(SIGY-XOM)12,12,6
     20            6 XOM=XOM+.250
     21              IF(SIGY-XOM)13,13,7
     22            7 XOM=XOM+.250
     23              IF(SIGY-XOM)14,14,8
     24            8 XOM=XOM+.250
     25              IF(SIGY-XOM)15,15,16
     26           11 S=((P(KL)+P(KL-1))/2.)
     27              TL=((QL(KL)+QL(KL-1))/2.)
     28              I=(S+.5)
     29              J=(TL+.5)
     30              QT=Q(I,J)
     31              RETURN
     32           12 A=.000518
     33              B=.911072
     34              C=.021714
     35              GO TO 17
     36           13 A=.009370
     37              B=.650280
     38              C=.078060
     39              GO TO 17
     40           14 A=.029202
     41              B=.482184
     42              C=.100252
     43              GO TO 17
     44           15 A=.044883
     45              B=.332108
     46              C=.122090
     47              GO TO 17
     48           16 A=.066359
     49              B=.233004
     50              C=.125390
     51           17 S=((P(KL)+P(KL-1))/2.)
     52              TL=((QL(KL)+QL(KL-1))/2.)
     53              I=S+.5
     54              J=TL+.5
     55              QT=(A*(Q(I-1,J-1)+Q(I+1,J-1)+Q(I-1,J+1)+Q(I+1,J+1)))+(B*(Q(I,J)))+
     56             X(C*(Q(I,J-1)+Q(I-1,J)+Q(I+1,J)+Q(I,J+1)))
     57              RETURN
     58           98 WRITE(3,50)
     59           50 FORMAT( '  INSUFFICIENT SOURCE FIELDS')
     60              RETURN
     61              END
```

CHART TITLE - SUBROUTINE DATE(D,TITL)



FORTRAN MODULE (LIST1,MAPSC)

CARD NO **** CONTENTS ****

```
      SUBROUTINE OPTSRC
      COMMON ALS(247),INIJ(200),ITRNON(50),JTO(50),II(200),
     XJJ(200),HI(20),IST(20),HLS(5),X(200),Y(200),VBAR(200),P(200),          6020
     XQL(200),CHI,ITO1,TO,N,T,DT,GS,NHLS,XMIN,XMAX,YMIN,YMAX,IBUG,DG,DS,
     XSIGZO,SIGZ,SIGDT,NG,L,TQ,I,J,U,V,DX,DY,NL,IR,KL,M,LL,KK,MM,S,TL,F,
     XA,B,TT,C,SIGY,DL,SIGZLN,HT,TI,QT,ITC,PI,K,LNO,C,BCHI,ZO,JST(20),       6050
     XPCHI,IPRINT,MAXP,OPT(50),HPT(50),NGRIDS,MJ                             6060
1000 FORMAT (41X,*POINT SOURCE IN GRID UNIT *)
      DO 2 I=1,247
    2 ALS(I)=0
      PCHI=0.
      CALL FILET(2,ALS,NUM)
      CALL FILET(1,ALS,NUM)
      IF (IBUG) 10,10,5
    5 WRITE (3,501) NUM,(ITRNON(I),JTO(I),I=1,NUM)
  501 FORMAT (2015)
   10 IF (NUM) 20,20,40
   20 RETURN
   40 DO 150 KI=1,NUM
      TQ=-TO
      I=ITRACA(KI)
      J=JTC(KI)
      NMAX=2*MAXP
      DO 50 KL=1,NMAX,2
      IP=INIJ(KL)
      JP=INIJ(KL+1)
      IF (I-IP) 50,60,50
   60 IF (J-JP) 50,70,50
   50 CONTINUE
   70 MK=KL/2 +1
      N=1
      AAA=SQRT(((P(1)-I)**2)+((QL(1)-J)**2))
      XX=AAA
      DO 80 L=2,K
      YY=SQRT(((P(L)-I)**2)+((QL(L)-J)**2))
      IF(XX-YY)81,81,90
   90 XX=YY
      N=N+1
   80 CONTINUE
   81 D=0.
      F=0.
      SUM=0.
      IF(N-2)100,100,110
  100 WRITE(3,1000)
  110 DO 120 L=2,N
      DL=SQRT(((P(L)-P(L-1))**2)+((QL(L)-QL(L-1))**2))
      SUM=SUM+VBAR(L)
      D=D+DL*GS
      F=F+1
      FT=(DL*GS)/VBAR(L)
      TQ=TQ+FT
  120 CONTINUE
      V=SUM/F
      N=1
      M=((TQ+TO)/T)+1
      CALL SIGZZ
      CALL SIGYY
      SIGY=SIGY*GS
      YY=YY*GS
      H=HPT(MK)
      IF (IBUG) 140,140,130
  130 WRITE (3,500) SIGY,SIGZ,YY,H,XX,V,DT,TQ,OPT(MK)
  500 FORMAT (1P10E12.3)
  140 E1=-.5*((H**2/SIGZ**2) + (YY**2/SIGY**2))
      E2=-.5*((H**2/SIGZ**2) + ((YY-.50*GS)**2/SIGY**2))
      E3=-.5*((H**2/SIGZ**2) + ((YY-.25*GS)**2/SIGY**2))
      E4=-.5*((H**2/SIGZ**2) + ((YY+.25*GS)**2/SIGY**2))
      E5=-.5*((H**2/SIGZ**2) + ((YY+.50*GS)**2/SIGY**2))
      E1=EXP(E1) + EXP(E2) + EXP(E3) + EXP(E4) + EXP(E5)
      E=(E1/5.)*EXP(TQ*ZO)
  150 PCHI=PCHI+(((OPT(MK)*2.)/(PI**2*V*SIGY*SIGZ))*E)
      RETURN
      END
```

CHART TITLE - SUBROUTINE OPTSRC

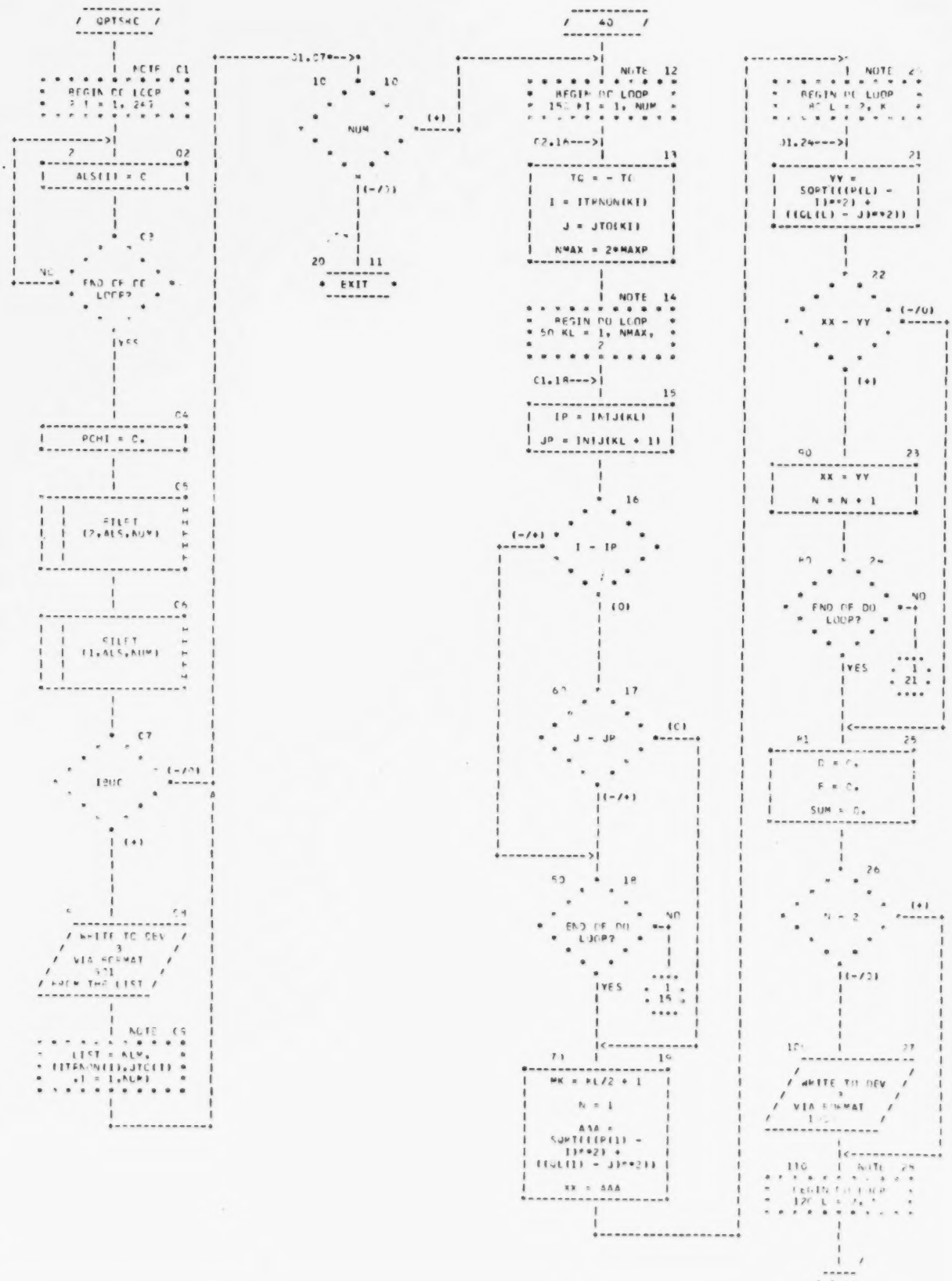
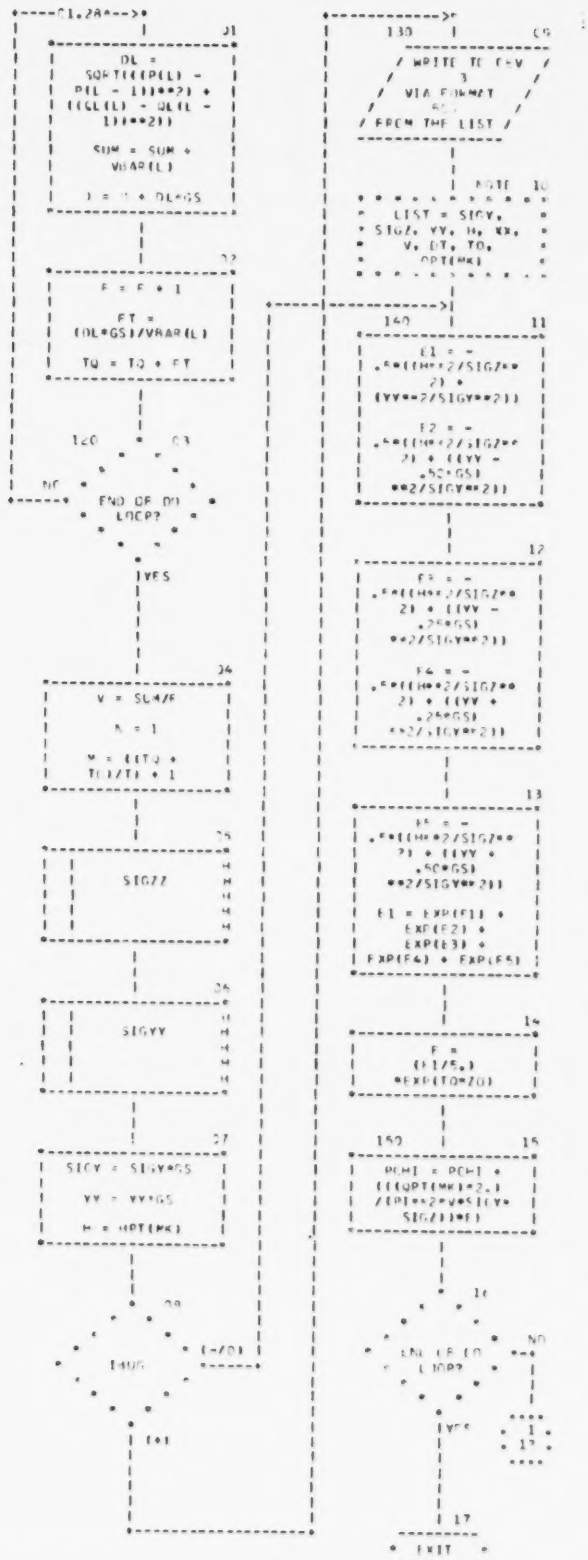


CHART TITLE = SUBROUTINE OPTSRC



FORTRAN MODULE (LESTE,AAPSC)

CARD NO	**** CONTENTS	****
1	SUBROUTINE TRAJEC(TITL)	
2	COMMON AL5(247),IN1J(200),ITRNCN(50),JTU(50),II(200),	
3	XJJ(200),XII(20),IST(20),HLSE(9),XI(200),YI(200),VMAR(200),P(200),	6020
4	XOL(20),CHI,ITC1,TO,H,T,DT,GS,XMES,XMIN,XMAX,YMIN,YMAX,IBUG,DG,DS,	
5	XSIGZ0,SIGZ,SECDT,NG,L,TQ,I,J,U,V,DX,DY,NL,IP,KL,MLL,KK,MM,S,TL,F,	
6	XA,B,TT,C,SIGY,DL,SIGZLN,MT,TI,QT,ITQ,PI,X,LNO,C,BCHI,ZO,JST(20),	6050
7	XPCHI,IPRINT,MAXP,CPT(50),HPT(51),NGRIDS,MJ	6060
8	COMMON/CCM01/ E04,I05	
9	COMMON/CCM02/ O(105,75)	
10	DIMENSION PSI(105,75),TITL(20)	
11	EQUIVALENCE(QQE1,13,PSI(1,1))	
12	9FAC(5*IC5) PSI	
13	TQ=C.	
14	TT=T	130
15	XEL(1)=II(NL)	00001400
16	YEL(1)=JJ(NL)	00001500
17	L=1	00001700
18	2 I=XEL(L)	00001800
19	J=YEL(L)	00001900
20	U=((PSI(I,J+1)-PSI(I,J-1))*DS)	00002000
21	V= -((PSI(I+1,J)-PSI(I-1,J))*DS)	00002100
22	3 DX=(U*DC)	00002200
23	DY=(V*DC)	00002300
24	DX1=ABS(DX)	00002400
25	DY1=ABS(DY)	00002500
26	IF(DX1-1.)4,4,5	00002600
27	4 IF(DY1-1.)6,6,5	00002700
28	5 DC=(DC/2.)	00002800
29	DT=(DT/2.)	00002900
30	GO TO 3	00003000
31	6 IF (DX1-.3) 995,995,996	
32	995 IF (DY1-.3) 997,997,996	
33	997 DC=2.*DC	
34	DT=2.*DT	
35	GO TO 3	
36	996 UV=((U**2)+(V**2))	
37	VPAR(L)=SQRT(UV)	00003200
38	L=L+1	00003300
39	IF(L-195) 117,113,113	
40	113 XEL(1)=XEL-1)+DX	
41	YEL(1)=YEL-1)+DY	
42	XEL(1)=XEL	
43	YEL(1)=YEL	
44	GO TO 130	
45	112 XEL(1)=XEL-1)+DX	340
46	YEL(1)=(YEL-1)+DY)	00003500
47	TC=TC+DT	360
48	IF(XEL)-XMIN)130,130,7	00003800
49	7 IF(XEL)-XMAX)8,130,130	00003900
50	8 IF(YEL)-YMIN)130,130,9	00004000
51	9 IF(YEL)-YMAX)10,130,130	00004100
52	10 IF (TC-TT) 2,11,11	420
53	11 TT=TT+T	430
54	IF(IC*-1200 407,407,912	
55	407 WRAC(5*IC5) PSI	
56	GO TO 2	
57	912 WRITE (3,9999)	460
58	XEL)=C.	
59	YEL)=C.	
60	9999 FORMAT (40X,*BREACHED END OF DATA BEFORE REACHING GRID BOUNDARY*)	461
61	130 P(L)=X(L)	00003470
62	QL(L)=YEL)	00003480
63	VPAR(L)=VPAR(L-1)	
64	LI=L	00003490
65	I4=1	00003500
66	L=2	00003510
67	KL=2	00003520
68	MM=0	00003530
69	IF(IMJ-12,12,1200	00003540
70	1200 WRITE(3,1205) LI,X(1),Y(1),X(LI),Y(LI)	00003550
71	CALL EQUMP (X(1),VPAR(2)0),5)	561
72	1205 FORMAT(2UX,110,4F13.2)	00003560
73	12 IF(XEL)-XEL-1))17,15,14	00003570
74	13 LL=2	00003580
75	GO TO 16	00003590
76	14 LL=3	00003600
77	GO TO 16	00003610
78	15 LL=1	00003620
79	16 IF(YEL)-YEL-1))17,19,18	00003630
80	17 KK=3	00003640
81	GO TO 20	00003650
82	18 KK=4	00003660
83	GO TO 20	00003670
84	19 KK=5	00003680
85	20 MM=KK+LL	00003690
86	GO TO(140,150,160,170,180,190,1130,1110,1120),MM	00003700
87	1130 IF(L-1)112,93,93	00003710
88	93 P(KL)=X(L)	00003720
89	QL(KL)=YEL)	00003730
90	VPAR(KL)=VPAR(L)	00003740
91	P(KL+1)=0.	00003750
92	QL(KL+1)=0.	00003760
93	94 K=KL	3780
94	GO TO 9A	00003790
95	140 IF(MJ-1) 141,141,142	00003800
96	142 WRITE(3,9998) XEL),YEL)	00003810
97	9998 FORMAT(5X,22HRE MOVEMENT POINT N AT,F10.4,F10.4)	00003820
98	141 L=L+1	00003830
99	GO TO 1130	00003840
100	150 LA=XEL)	00003850
101	KL=LK	00003860
102	*=KL+1	00003870
103	IF(XEL)-5)21,21,22	00003880
104	21 IF(XEL-1)-5)22,23,23	00003890
105	22 L=L+1	00003900
106	GO TO 1130	00003910
107	23 P(KL)=5	00003920
108	QL(KL)=YEL)	00003930
109	VPAR(KL)=VPAR(L)	00003940
110	KL = KL + 1	00003950
111	L=L+1	00003960
112	GO TO 1130	00003970
113	16 LA=XEL)	00003980

```
CARD NO  ****                    CONTENTS                    ****

                XL=LX                                                  00000990
                S=XL+.5                                                00001000
                IF(X(L)-S)25,24,24                                     00001010
             24 IF(X(L-1)-S)26,26,25                                   00001020
             25 L=L+1                                                  00001030
                GO TO 1130                                             00001040
             26 P(KL)=S                                                00001050
                QL(KL)=Y(L)                                            00001060
                VBAR(KL)=VBAR(L)                                       00001070
                KL=KL+1                                                00001080
                L=L+1                                                  00001090
                GO TO 1130                                             00001100
            170 LY=Y(L)                                                00001110
                YL=LY                                                  00001120
                TL=YL+.5                                               00001130
                IF(Y(L)-TL)27,27,28                                    00001140
             27 IF(Y(L-1)-TL)28,29,29                                  00001150
             28 L=L+1                                                  00001160
                GO TO 1130                                             00001170
             29 P(KL)=X(L)                                             00001180
                QL(KL)=TL                                              00001190
                VBAR(KL)=VBAR(L)                                       00001200
                KL=KL+1                                                00001210
                L=L+1                                                  00001220
                GO TO 1130                                             00001230
           1100 LY=Y(L)                                                00001240
                YL=LY                                                  00001250
                TL=YL+.5                                               00001260
                IF(Y(L)-TL)30,31,31                                    00001270
             31 IF(Y(L-1)-TL)32,32,30                                  00001280
             30 L=L+1                                                  00001290
                GO TO 1130                                             00001300
             32 P(KL)=X(L)                                             00001310
                QL(KL)=TL                                              00001320
                VBAR(KL)=VBAR(L)                                       00001330
                KL=KL+1                                                00001340
                L=L+1                                                  00001350
                GO TO 1130                                             00001360
            140 LX=X(L)+.5                                             00001370
                LXP=X(L-1)+.5                                          00001380
                LY=Y(L)+.5                                             00001390
                LYP=Y(L-1)+.5                                          00001400
                IF (LX-LXP) 33,34,33                                   00001410
             33 M=M+1                                                  00001420
             34 IF (LY-LYP) 35,36,35                                   00001430
             35 M=M+2                                                  00001440
             36 IF (M) 37,37,38                                        00001450
             37 L=L+1                                                  00001460
                GO TO 1130                                             00001470
             38 XL=LX                                                  00001480
                YL=LY                                                  00001490
                S=XL+.5                                                00001500
                TL=YL+.5                                               00001510
             42 F=((Y(L)-Y(L-1))/(X(L)-X(L-1)))                        00001540
                GO TO(41,42,43),M                                      00001550
             41 P(KL)=S                                                00001560
                QL(KL)=((F*(S-X(L-1)))+Y(L-1))                         00001570
                VBAR(KL)=VBAR(L)                                       00001580
                GO TO 44                                               00001590
             42 QL(KL)=TL                                              00001600
                P(KL)=(((TL-Y(L-1))/F)+X(L-1))                         00001610
                VBAR(KL)=VBAR(L)                                       00001620
             44 KL=KL+1                                                00001630
                L=L+1                                                  00001640
                M=0                                                    00001650
                GO TO 1130                                             00001660
             43 A=(((TL-Y(L-1))/F)+X(L-1))                             00001670
                B=((F*(S-X(L-1)))+Y(L-1))                              00001680
                IF(A-S)45,45,46                                        00001690
             45 P(KL)=S                                                00001700
                P(KL+1)=A                                              00001710
                QL(KL+1)=TL                                            00001720
                VBAR(KL)=VBAR(L)                                       00001730
                VBAR(KL+1)=VBAR(KL)                                    00001740
                QL(KL)=B                                               00001750
                GO TO 47                                               00001760
             46 P(KL)=A                                                00001770
                QL(KL)=TL                                              00001780
                P(KL+1)=S                                              00001790
                QL(KL+1)=B                                             00001800
                VBAR(KL)=VBAR(L)                                       00001810
                VBAR(KL+1)=VBAR(KL)                                    00001820
             47 KL=KL+2                                                00001830
                L=L+1                                                  00001840
                M=0                                                    00001850
                GO TO 1130                                             00001860
            190 LX=X(L)+.5                                             00001870
                LXP=X(L-1)+.5                                          00001880
                LY=Y(L)+.5                                             00001890
                LYP=Y(L-1)+.5                                          00001900
                IF (LX-LXP) 48,49,48                                   00001910
             48 M=M+1                                                  00001920
             49 IF (LY-LYP) 50,51,50                                   00001930
             50 M=M+2                                                  00001940
             51 IF (M) 52,52,53                                        00001950
             52 L=L+1                                                  00001960
                GO TO 1130                                             00001970
             53 XL=LX                                                  00001980
                YL=LY                                                  00001990
                S=XL+.5                                                00002000
                TL=YL+.5                                               00002010
             55 F=((Y(L)-Y(L-1))/(X(L)-X(L-1)))                        00002020
                GO TO(56,57,58),M                                      00002030
             56 P(KL)=S                                                00002040
                QL(KL)=((F*(S-X(L-1)))+Y(L-1))                         00002050
                VBAR(KL)=VBAR(L)                                       00002060
                GO TO 61                                               00002070
             57 QL(KL)=TL                                              00002080
                P(KL)=(((TL-Y(L-1))/F)+X(L-1))                         00002090
                VBAR(KL)=VBAR(L)                                       00002100
             61 KL=KL+1                                                00002110
                L=L+1                                                  00002120
                M=0                                                    00002130
                GO TO 1130                                             00002140
             58 A=(((TL-Y(L-1))/F)+X(L-1))                             00002150
                B=((F*(S-X(L-1)))+Y(L-1))                              00002160
```

```
CARD NO.  ****  CONTENTS  ****
                IF(A-S)59,60,60                                          00002160
             60 P(KL)=S                                                  00002170
                P(KL+1)=A                                                00002180
                QL(KL)=R                                                 00002190
                QL(KL+1)=TL                                              00002200
                VPAR(KL)=VPAR(L)                                         00002210
                VPAR(KL+1)=VPAR(KL)                                      00002220
                GO TO 62                                                 00002230
             59 P(KL)=A                                                  00002240
                P(KL+1)=S                                                00002250
                QL(KL+1)=R                                               00002260
                QL(KL)=TL                                                00002270
                VPAR(KL)=VPAR(L)                                         00002280
                VPAR(KL+1)=VPAR(KL)                                      00002290
             62 KL=KL+2                                                  00002300
                L=L+1                                                    00002310
                M=0                                                      00002320
                GO TO 1130                                               00002330
           1110 LX=X(L)+.5                                               00002340
                LXM=X(L-1)+.5                                            00002350
                LY=Y(L)+.5                                               00002360
                LYM=Y(L-1)+.5                                            00002370
                IF (LX-LXM) 63,66,63                                     00002380
             63 M=M+1                                                    00002390
             64 IF (LY-LYM) 65,66,65                                     00002400
             65 M=M+2                                                    00002410
             66 IF (M) 67,67,68                                          00002420
             67 L=L+1                                                    00002430
                GO TO 1130                                               00002440
             68 XL=LX                                                    00002450
                YL=LYM                                                   00002460
                S=XL+.5                                                  00002470
                TL=YL+.5                                                 00002480
             70 F=((Y(L)-Y(L-1))/(X(L)-X(L-1)))                          00002490
                GO TO(71,72,73),M                                        00002500
             71 P(KL)=S                                                  00002510
                QL(KL)=((F*(S-X(L-1)))+Y(L-1))                           00002520
                VPAR(KL)=VPAR(L)                                         00002530
                GO TO 77                                                 00002540
             72 QL(KL)=TL                                                00002550
                P(KL)=(((TL-Y(L-1))/F)+X(L-1))                           00002560
                VPAR(KL)=VPAR(L)                                         00002570
             77 KL=KL+1                                                  00002580
                L=L+1                                                    00002590
                M=0                                                      00002600
                GO TO 1130                                               00002610
             73 A=(((TL-Y(L-1))/F)+X(L-1))                               00002620
                S=((F*(S-X(L-1)))+Y(L-1))                                00002630
                IF(A-S)76,75,74                                          00002640
             74 P(KL)=S                                                  00002650
                P(KL+1)=A                                                00002660
                QL(KL)=R                                                 00002670
                QL(KL+1)=TL                                              00002680
                VPAR(KL)=VPAR(L)                                         00002690
                VPAR(KL+1)=VPAR(KL)                                      00002700
                GO TO 77                                                 00002710
             75 P(KL)=A                                                  00002720
                P(KL+1)=S                                                00002730
                QL(KL+1)=R                                               00002740
                QL(KL)=TL                                                00002750
                VPAR(KL)=VPAR(L)                                         00002760
                VPAR(KL+1)=VPAR(KL)                                      00002770
             76 KL=KL+2                                                  00002780
                L=L+1                                                    00002790
                M=0                                                      00002800
                GO TO 1130                                               00002810
           1120 LX=X(L)+.5                                               00002820
                LXM=X(L-1)+.5                                            00002830
                LY=Y(L)+.5                                               00002840
                LYM=Y(L-1)+.5                                            00002850
                IF (LX-LXM) 78,79,78                                     00002860
             78 M=M+1                                                    00002870
             79 IF (LY-LYM) 80,81,80                                     00002880
             80 M=M+2                                                    00002890
             81 IF (M) 82,82,83                                          00002900
             82 L=L+1                                                    00002910
                GO TO 1130                                               00002920
             83 XL=LXM                                                   00002930
                YL=LYM                                                   00002940
                S=XL+.5                                                  00002950
                TL=YL+.5                                                 00002960
             86 F=((Y(L)-Y(L-1))/(X(L)-X(L-1)))                          00002970
                GO TO(86,87,88),M                                        00002980
             85 P(KL)=S                                                  00002990
                QL(KL)=((F*(S-X(L-1)))+Y(L-1))                           00003000
                VPAR(KL)=VPAR(L)                                         00003010
                GO TO 89                                                 00003020
             87 QL(KL)=TL                                                00003030
                P(KL)=(((TL-Y(L-1))/F)+X(L-1))                           00003040
                VPAR(KL)=VPAR(L)                                         00003050
             89 KL=KL+1                                                  00003060
                L=L+1                                                    00003070
                M=0                                                      00003080
                GO TO 1130                                               00003090
             84 A=(((TL-Y(L-1))/F)+X(L-1))                               00003100
                S=((F*(S-X(L-1)))+Y(L-1))                                00003110
                IF(A-S)90,91,91                                          00003120
             90 P(KL)=A                                                  00003130
                P(KL+1)=S                                                00003140
                QL(KL)=TL                                                00003150
                QL(KL+1)=R                                               00003160
                VPAR(KL)=VPAR(L)                                         00003170
                VPAR(KL+1)=VPAR(KL)                                      00003180
                GO TO 92                                                 00003190
             91 P(KL)=S                                                  00003200
                P(KL+1)=A                                                00003210
                QL(KL)=R                                                 00003220
                QL(KL+1)=TL                                              00003230
                VPAR(KL)=VPAR(L)                                         00003240
                VPAR(KL+1)=VPAR(KL)                                      00003250
             92 KL=KL+2                                                  00003260
                L=L+1                                                    00003270
                M=0                                                      00003280
                GO TO 1130                                               00003290
                END                                                      00003300
```

CHART TITLE - SLERCLTINE TRAJEC(TITL)

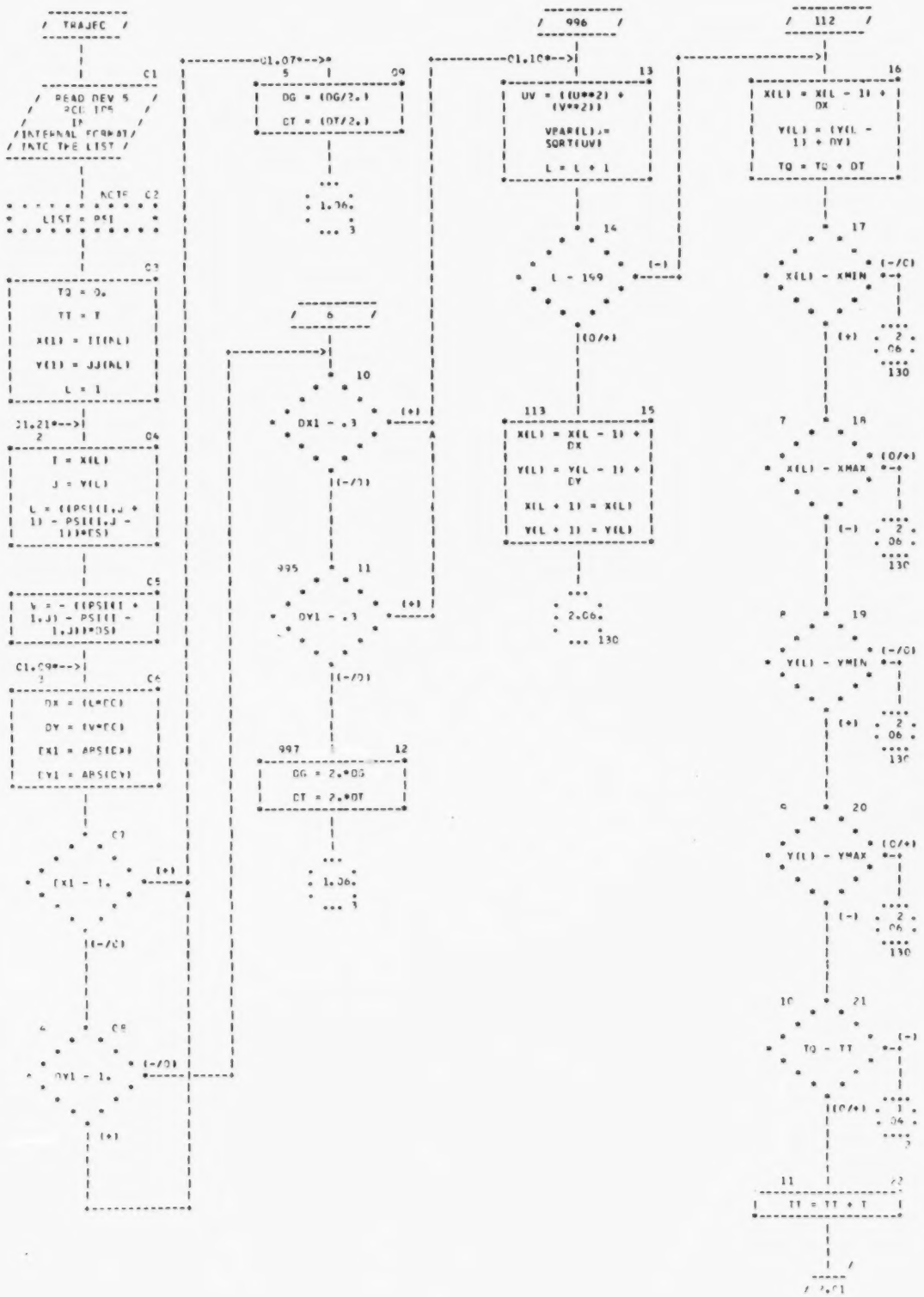


CHART TITLE - SUBROUTINE TRAJEC(TITL)

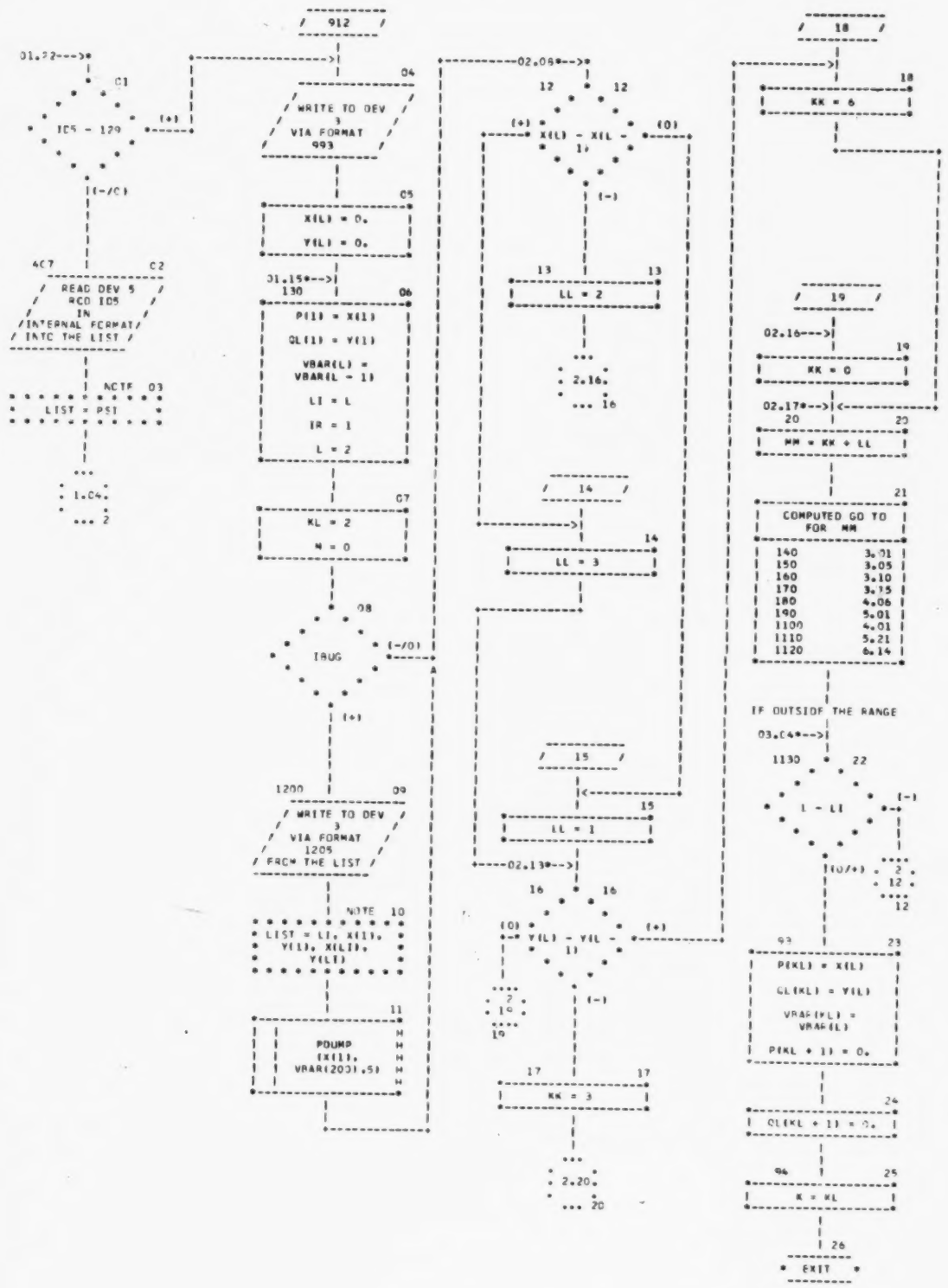


CHART TITLE - SUBROUTINE TRAJECTITL)

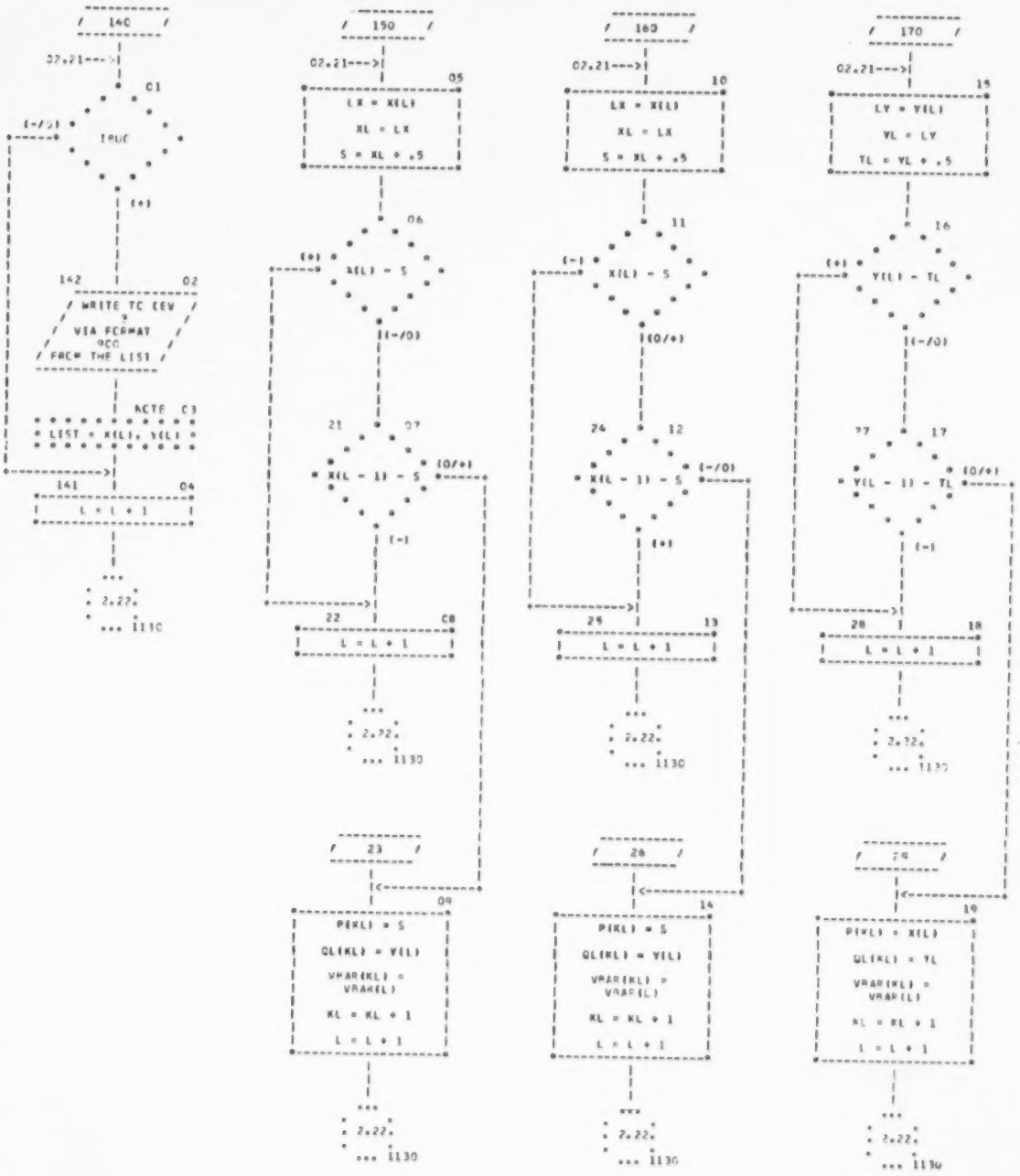


CHART TITLE - SUBROUTINE TRAJEC(TITL)

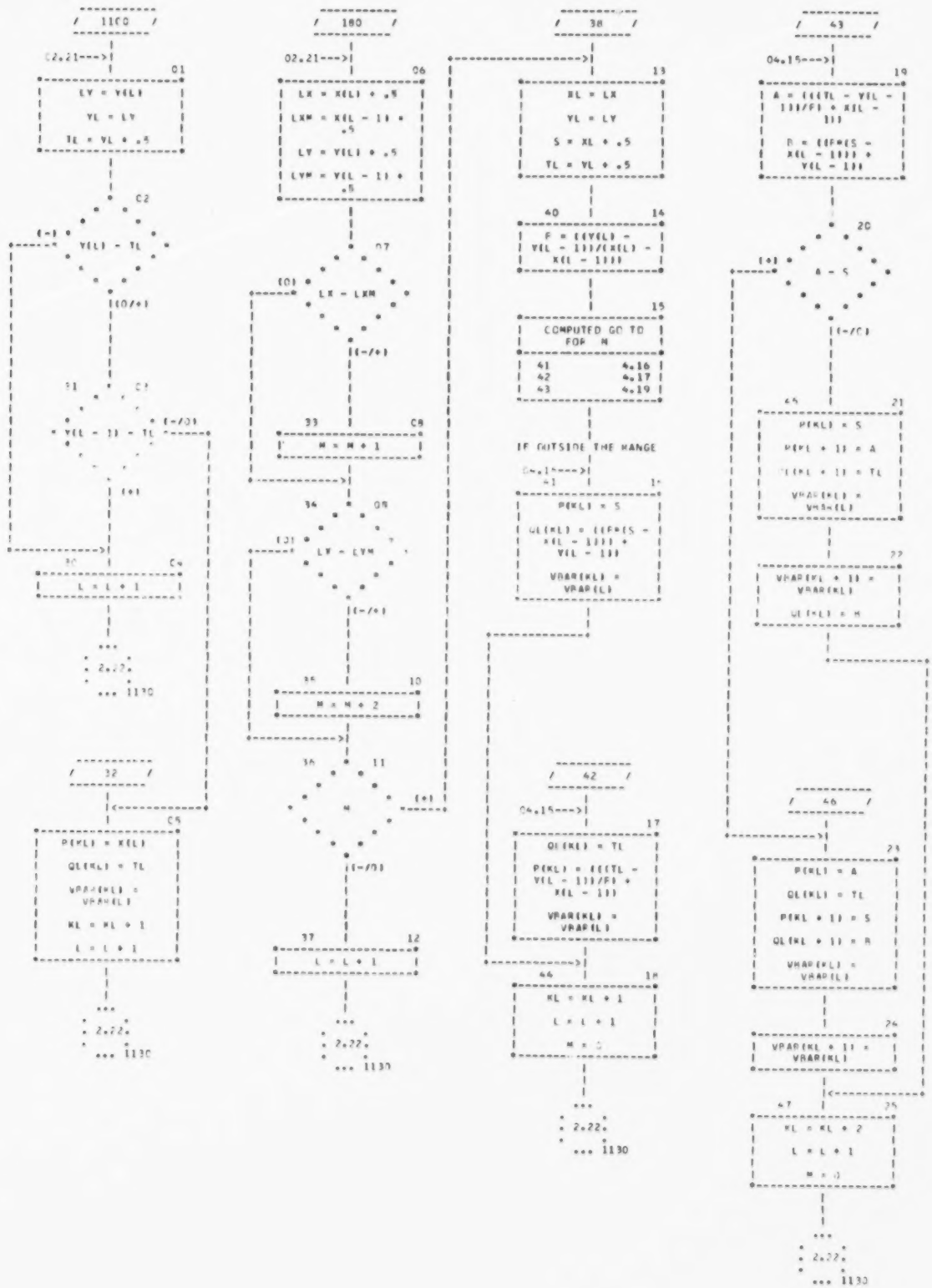
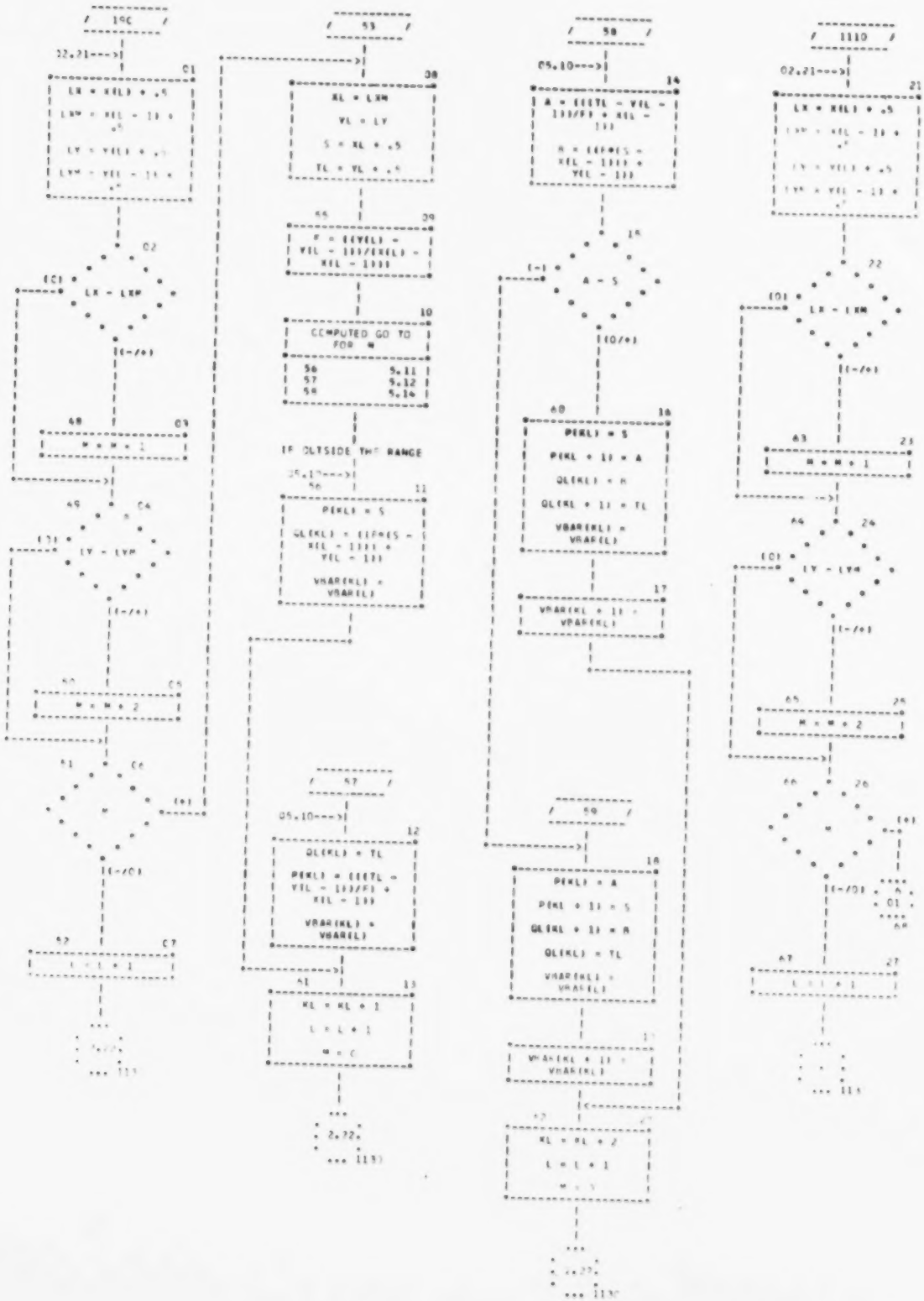


CHART TITLE - SUBROUTINE TRAJECT(ITL)



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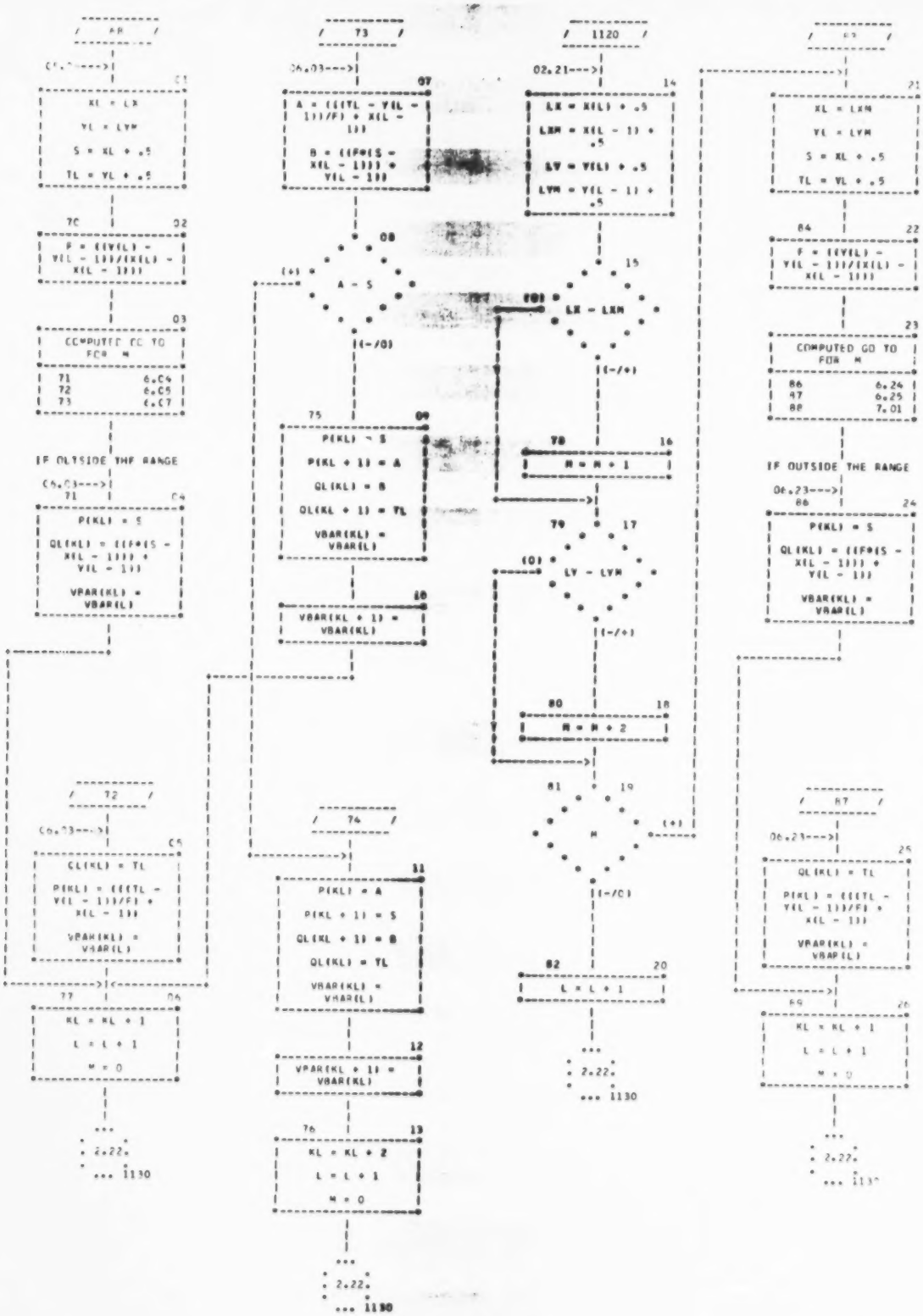
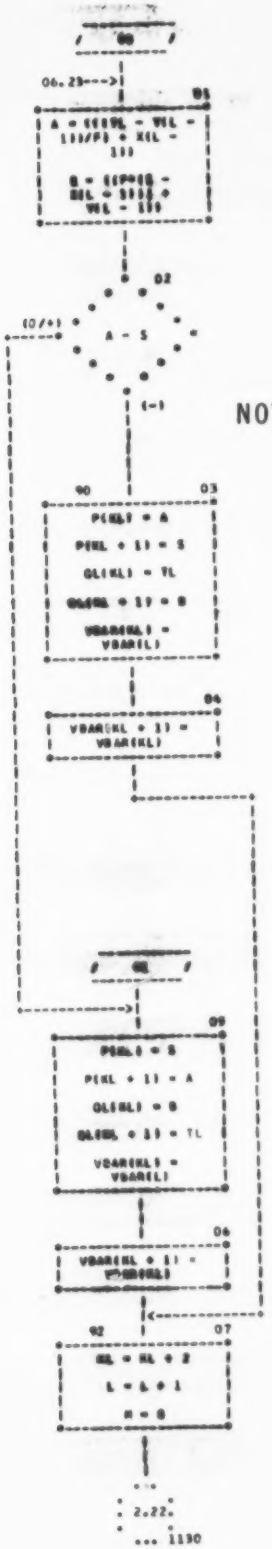


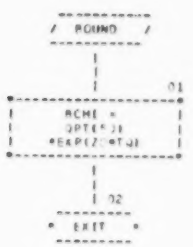
CHART TITLE - SUBROUTINE TRAJECTYTL1



NOT REPRODUCIBLE

FORTRAN MODULE ELIST1,A4MSG1

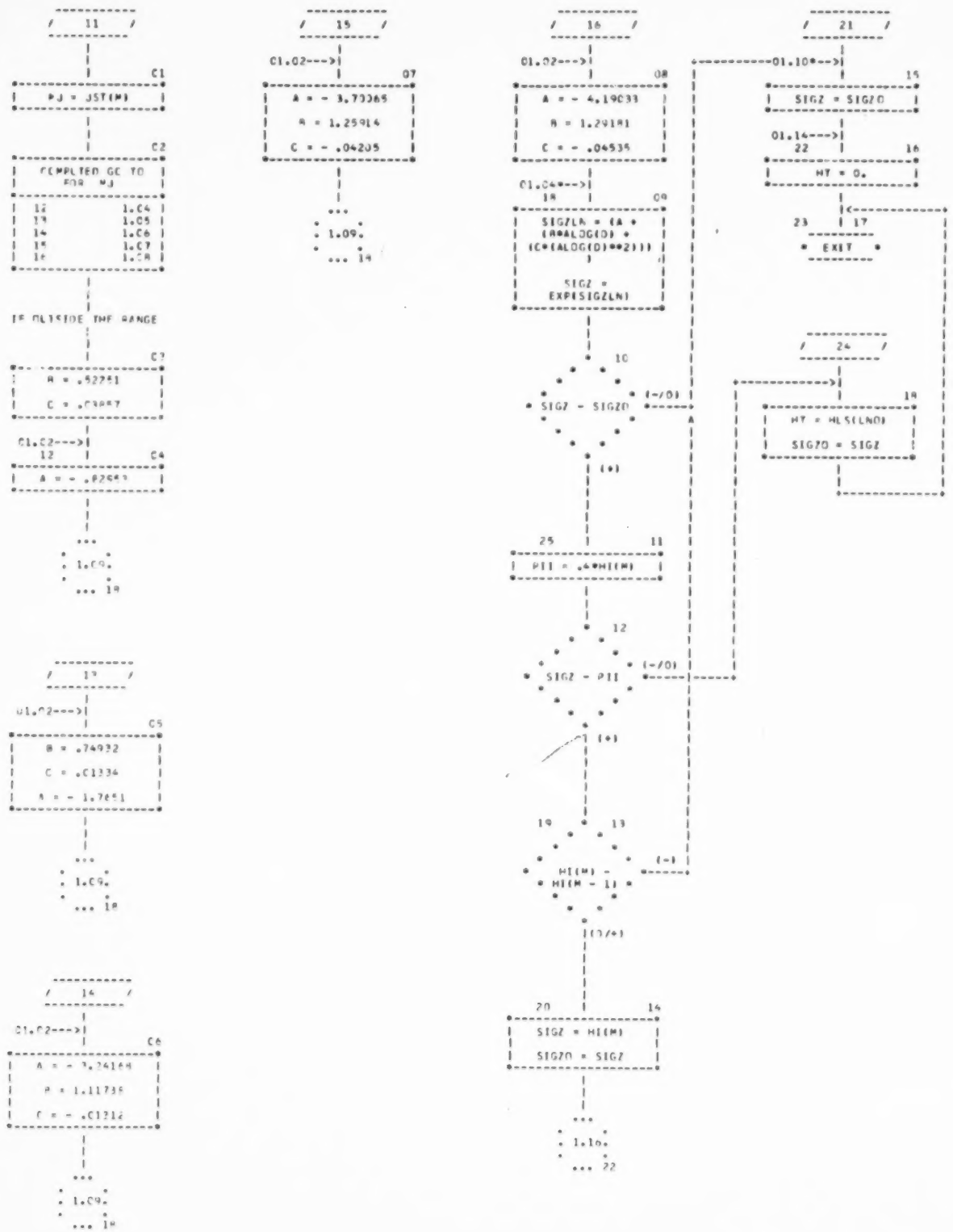
CARD NO	**** CONTENTS	****
1	SUBROUTINE BOUND	
2	COMMON ALS(247),INIJ(2001,ITRNCN(50),JTO(50),III(200),	
3	XJJJ(200),NII(20),ISTI(20),MLSI(5),XI(200),YI(200),VHAR(200),PI(200),	6020
4	XQL(200),CPI,ITCL,TO,N,T,DT,DS,XMIN,XMAX,YMIN,YMAX,IPUG,DG,DS,	
5	XSIGZO,SIGZ,SIGDT,NG,L,TQ,I,J,U,V,DX,DY,NL,IR,KL,MLL,KK,MM,S,TL,P,	
6	XA,B,TT,C,SIGY,DL,SIGZLN,MT TI,JT,ITO,PI,K,LNO,C,BCHI,ZO,JST(20),	6050
7	XPCHI,)PRINT,MAXP,QPT(50),MPT(50),NGRIDS,MJ	6060
8	BC=1-QPT(50)*EXP(ZO*TQ)	
9	RETURN	
10	END	



FORTRAN MODULE (LIST1,NAMSC)

CARD NO	****	CONTENTS	****
1		SUBROUTINE SIGZZ	4010
2		COMMON ALS(247),INIJ(200),ITRANSN(50),JT(50),II(200),	
3		XJJ(200),HI(200),IST(20),HLS(5),X(200),Y(200),VMAM(200),P(200),	4020
4		XOL(200),CHI,ITO1,TO,N,T,DT,GS,NHLS,XMIN,XMAX,YMIN,YMAX,IHUG,IG,ES,	
5		XSIGZO,SIGZ,SIGDT,AG,L,TQ,I,J,U,V,DX,DY,NL,IR,KL,M,LL,KK,MM,S,TL,F,	
6		XA,B,TT,D,SIGY,DL,SIGZLN,HT,TI,DT,IEQ,PI,K,LNO,C,BCHI,ZO,JST(20),	4050
7		XPCHI,IPRINT,MAXP,QPT(50),APT(50),NGRIDS,MJ	4060
8	11	MJ=JST(M)	4080
9		GO TO (12,13,14,15,16),MJ	4090
10		B=.82251	4100
11		C=.03857	4110
12	12	A=-.82953	4120
13		GO TO 18	4130
14	13	B=.74932	4140
15		C=.01334	4150
16		A=-1.7451	4160
17		GO TO 18	4170
18	14	A=-3.2416	4180
19		B=1.11738	4190
20		C=-.01312	4200
21		GO TO 18	4210
22	15	A=-3.70065	4220
23		B=1.25914	4230
24		C=-.04205	4240
25		GO TO 18	4250
26	16	A=-4.19043	4260
27		B=1.29141	4270
28		C=-.04535	4280
29	18	SIGZLN=(A+(B*ALOG(O)+(C*(ALOG(O)**2))))	4290
30		SIGZ=EXP(SIGZLN)	4300
31		IF (SIGZ-SIGZO) 21,21,25	4310
32	25	PII=.4*HI(M)	4320
33		IF (SIGZ-PII) 24,24,19	4330
34	19	IF (HI(M)-HI(M-1))21,20,20	4340
35	20	SIGZ=HI(M)	4350
36		SIGZO=SIGZ	4360
37		GO TO 22	4370
38	21	SIGZ=SIGZO	4380
39	22	HT=0.	4390
40	23	RETURN	4400
41	24	HT=HLS(LNO)	4410
42		SIGZO=SIGZ	4420
43		GO TO 23	4430
44		END	4440

CHART TITLE = SUBROUTINE SIGZZ



03/15/71 INPLT LISTING AUTOFLOW CHART SET - COMB.ENG

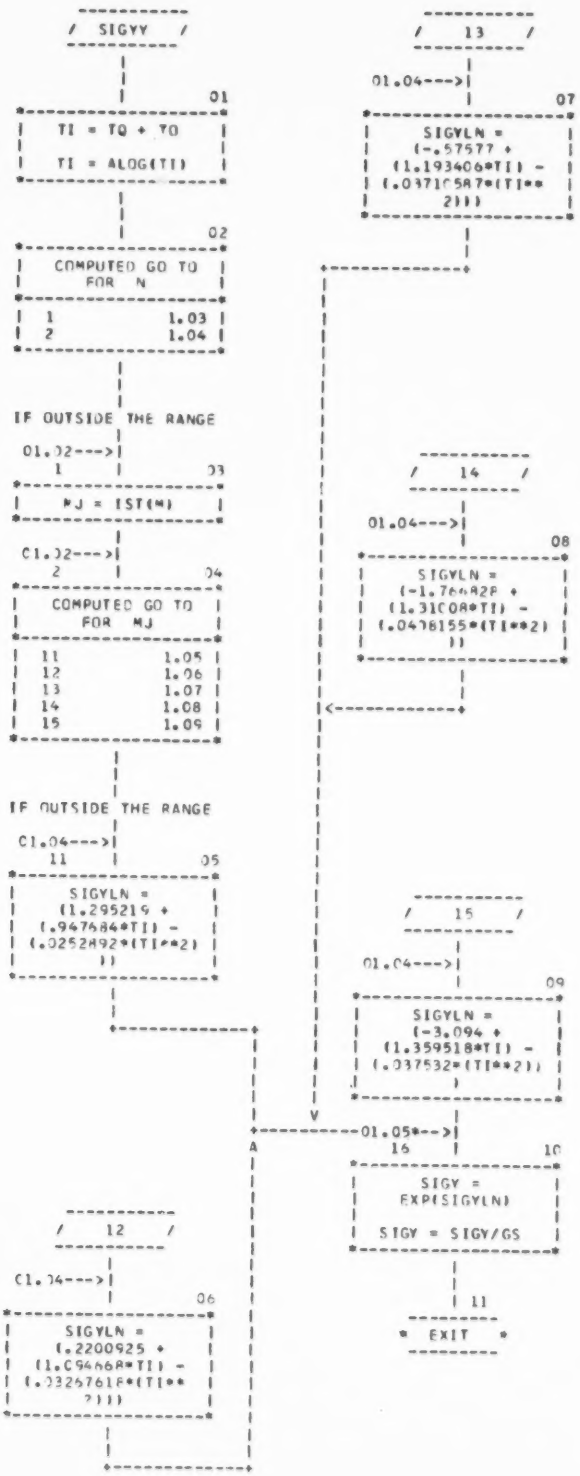
FORTRAN MODULE (LISTI,MAMSG)

CARD NO **** CONTENTS ****

```
      SUBROUTINE SIGYY
      COMMON ALS(247),IMIJ(200),ITRNON(50),JTO(50),II(200),
     XJJ(200),HI(20),IST(20),HLS(5),X(200),Y(200),VBAR(200),P(200),
     XQL(200),CHI,ITOI,TO,N,T,DT,GS,NHLS,XMIN,XMAX,YMIN,YMAX,IBUG,DG,DS,
     XSIGZO,SIGZ,SIGDT,NG,L,TQ,I,J,U,V,DX,DY,NL,IF,KL,M,LL,KK,MM,S,TL,F,
     XA,B,TT,C,SIGY,DL,SIGZLN,HT,TI,QT,ITO,PI,K,LN),C,BCHI,ZO,JST(20),
     XPCHI,IPRINT,MAXP,QPT(50),HPT(50),NGRIDS,MJ
      TI=TQ+TC
      TI=ALOG(TI)
      GO TO(1,2),N
    1 MJ=IST(M)
    2 GO TO(11,12,13,14,15),MJ
   11 SIGYLN=(1.295219+(.947684*TI)-(.0252892*(TI**2)))
      GO TO 16
   12 SIGYLN=(.2200925+(1.094668*TI)-(.03267618*(TI**2)))
      GO TO 16
   13 SIGYLN=(-.57577+(1.193406*TI)-(.0371687*(TI**2)))
      GO TO 16
   14 SIGYLN=(-1.764828+(1.31008*TI)-(.0408155*(TI**2)))
      GO TO 16
   15 SIGYLN=(-3.094+(1.359518*TI)-(.037532*(TI**2)))
   16 SIGY=EXP(SIGYLN)
      SIGY=SIGY/GS
      RETURN
      END
```

6020 6050 6060

CHART TITLE - SUBROUTINE SIGYY

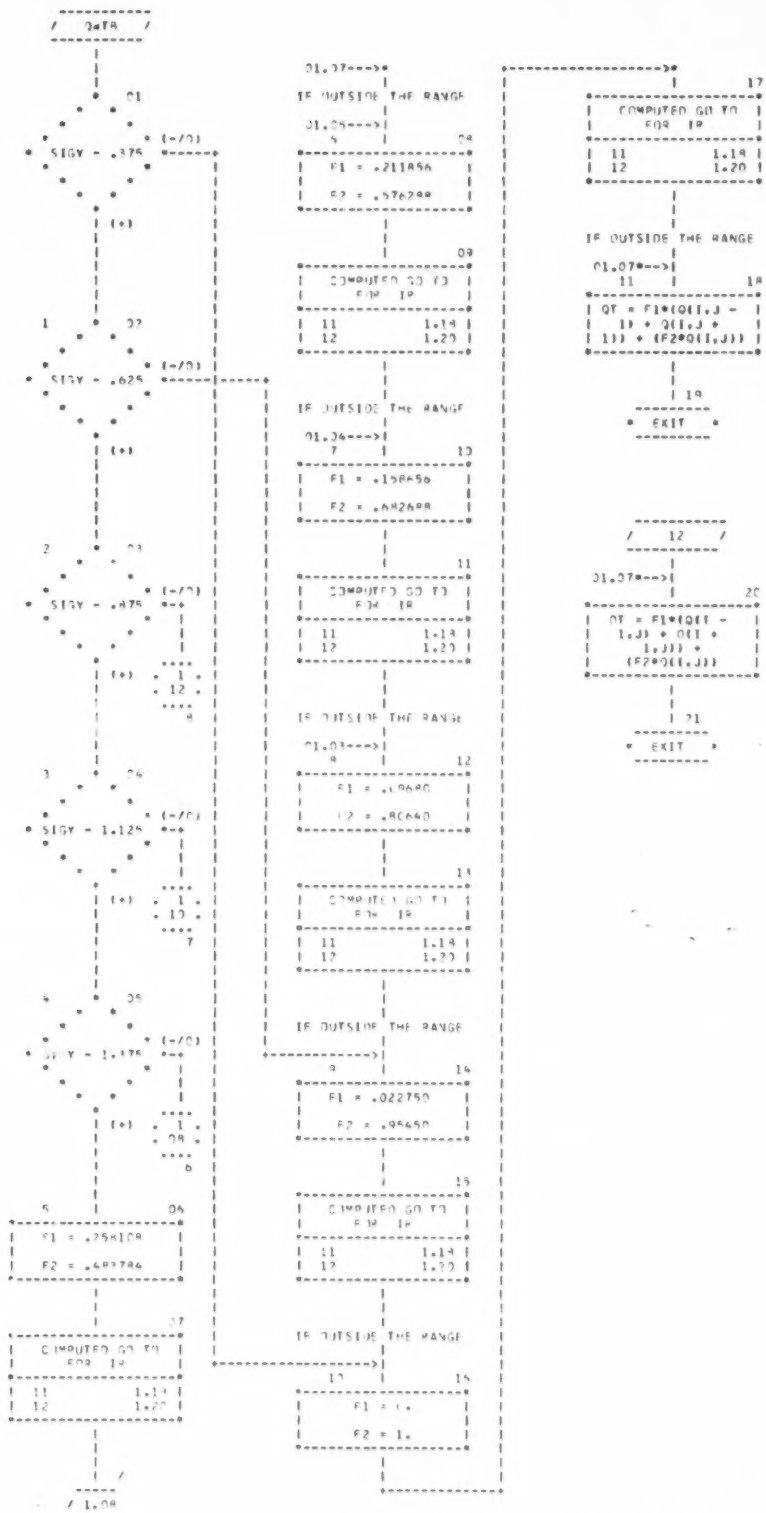


CONTENTS

CARD NO ****

```
      1            SUBROUTINE QWTB  (Q,TITL)
      2            COMMON ALS(247),INIJ(200),ITRNON(50),JTO(50),II(200),                  6020
      3           XJJ(200),HI(20),IST(20),HLS(5),X(200),Y(200),VBAR(200),P(200),
      4           XOL(200),CHI,ITOL,TO,N,T,DT,GS,NHLS,XMIN,XMAX,YMIN,YMAX,IBUG,DG,DS,
      5           XSIGZO,SIGZ,SIGDT,NG,L,TO,I,J,J,V,DX,DY,NL,IR,KL,M,LL,KK,MM,S,TL,F,    6050
      6           XA,B,TT,O,SIGY,OL,SIGZLN,HT,TI,QT,ITO,PI,K,LNO,C,BCHI,ZO,JST(20),      6060
      7           XPCHI,IPRINT,MAXP,QPT(50),HPT(50),NGRIDS,MJ
      8            DIMENSION Q(105,75),TITL(20)
      9            IF(SIGY-.375)10,10,1
     10          1 IF(SIGY-.625)9,9,2
     11          2 IF(SIGY-.875)8,8,3
     12          3 IF(SIGY-1.125)7,7,4
     13          4 IF(SIGY-1.375)6,6,5
     14          5 F1=.258108
     15            F2=.483784
     16            GO TO(11,12),IR
     17          6 F1=.211856
     18            F2=.576288
     19            GO TO(11,12),IR
     20          7 F1=.158656
     21            F2=.682688
     22            GO TO(11,12),IR
     23          8 F1=.09680
     24            F2=.80640
     25            GO TO(11,12),IR
     26          9 F1=.022750
     27            F2=.95450
     28            GO TO(11,12),IR
     29         10 F1=0.
     30            F2=1.
     31            GO TO(11,12),IR
     32         11 QT=F1*(Q(I,J-1)+Q(I,J+1))+(F2*Q(I,J))
     33            RETURN
     34         12 QT=F1*(Q(I-1,J)+Q(I+1,J))+(F2*Q(I,J))
     35            RETURN
     36            END
```

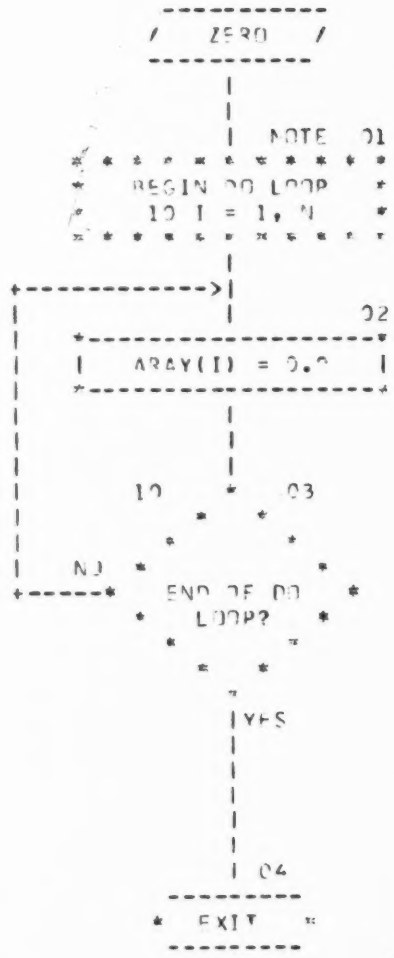
CHART TITLE - SUBROUTINE DWTB(D,TITL)



FORTRAN MODULE (LIST1,NAMSO)

CARD NO **** CONTENTS ****

```
1                SUBROUTINE ZERO(ARAY,N)
2                DIMENSION ARAY(1)
3                DO 10  I=1,N
4                ARAY(I)=0.0
5             10 CONTINUE
6                RETURN
7                END
```



FORTRAN MODULE (LIST1,NAMSC)

```
CARD NO  ****                    CONTENTS                    ****
      1          SUBROUTINE WINDS
      2          COMMON/COM01/ I04,I05
      3          COMMON/COM02/ Q(105,75)
      4          DIMENSION G(105,75),PNS(106,77),PEW(106,77)
      5          EQUIVALENCE(Q(1,1),G(1,1))
      6        100 FORMAT(3F10.2)
      7        101 FORMAT(20F4.0)
      8          DO 320   J=1,77
      9          READ(1,101)   (PNS(I,J),I=1,106)
     10        320 CONTINUE
     11          DO 330    J=1,77
     12          READ(1,101)   (PEW(I,J),I=1,106)
     13        330 CONTINUE
     14          G=.5622/300.0
     15          I05=1
     16          DO 30    LPP=1,15
     17          CALL ZERO(G,7875)
     18          READ(1,100)       U0,V0
     19        C THE SIGNS OF A AND B DEPEND ON THE INITIAL WIND DIRECTION ESTIMATE.
     20          A=V0
     21          B=U0
     22          DO 20  I=1,104
     23          SUM3=0.
     24          SUM4=0.
     25          DO 21    J=1,74
     26        C GRADIENT OF PHI EAST WEST IN I DIRECTION
     27          DEWI=PEW(I+1,J)-PEW(I,J)
     28        C GRADIENT OF PHI NORTH SOUTH IN I DIRECTION
     29          DNSI=PNS(I+1,J)-PNS(I,J)
     30          DEWI2=PEW(I+1,J+1)-PEW(I,J+1)
     31          DNSI2=PNS(I+1,J+1)-PNS(I,J+1)
     32          SUM3=(DEWI+DEWI2)*.5        +SUM3
     33          SUM4=(DNSI+DNSI2)*.5        + SUM4
     34          G(I,J)=(A*(+B*J+C*U0+SUM3+C*V0+SUM4)+1524.
     35       21 CONTINUE
     36       20 CONTINUE
     37          WRITE(5*I05)  G
     38       30 CONTINUE
     39          RETURN
     40          END
```

CHART TITLE - SUBROUTINE WINDS